Inland Waters and Their Sea Approaches

EROSION OF RIVER BANKS IN ITS RELATIONSHIP TO INLAND WATERS AND THEIR SEA APPROACHES, ITS EFFECT ON LAND CONSERVANCY, NAVIGATION, PUBLIC HEALTH, PROSPERITY, POLITICS, REVENUE, AND ALL RIVERAIN PROPERTY

By

ENGINEER LIEUT. COMMANDER W. A. WILLIAMS
M. I. E. (Ind.), R. I. M.

Engineer and Ship Surveyor to the Government of Bengal

Qualified to examine Engineers for certificates of competency in the Mercantile Marine.

Calcutta:
W. NEWMAN & CO., LTD., 4, DALHOUSIE SQUARE
19[illegible]

PREFACE

The author's excuse for producing this work is that he feels the subject is not receiving the attention its importance deserves, and that he has had such a varied collection of experiences as to lead him to believe he could throw some light upon the matter and indicate, not only the disease, but the cure.

The author has served at sea and on rivers; was twice seconded into the Bombay Port Trust during construction of new docks and reclamations; was Assistant to the, and some time acting as, Superintending Engineer to the Government of Burma, and has been responsible that sea-going vessels have not overloaded in waters whose density might vary from that of sea to freshness.

The author, in trying to establish general rules for the control of waterways, would like it to be borne in mind that each waterway will require its own special treatment, firstly because of inconsistencies in the material of its bed, and secondly, because of the reversal, or alteration of speed, of its water. Temperature and density effects will differ in most waters too, so that each will require proper attention under this heading.

Canals require very careful design to keep them clean and safe from shoaling.

W. A. WILLIAMS

CHITTAGONG, *13th February, 1922.*

ILLUSTRATIONS

(At end of the Book)

Also six highly interesting sketches prepared by Captain G. R. Simpson showing River Routes which have been abandoned

CONTENTS

CHAPTER I.

A Criticism of Existing River Beds.

Drawing Mark I shews a river with tributaries. The river banks are shewn close together for convenience of illustration and proof, but in actual conditions these banks, when (as usually) neglected, are far apart and a most valuable part of the land is under water to the disadvantage of both land and water. In Bengal hundreds of square miles, which could be adding to the wealth and comfort of the population, are shiftingly under water, whilst this water, which should be the cheap carrier of produce, is only haltingly navigable for the shallowest drafted and most expensive type of craft procurable. How all this is avoidable is shewn in drawing Mark I. The why and the wherefore will be shewn in subsequent chapters. It will be noticed in fig. I, Mark I, that the pilot's course in every case hugs the concave bank whilst the river bed has shoaled up to the opposite side. It will be also noticed that the pilot's course in fig. 2, Mark I, hugs the convex side whilst the now reduced width of the river with its equal sectional area has become very much deeper. It will be further noticed that the pilot's course has become shorter and much less devious than in fig. I, Mark I. It will be also readily

seen what a gigantic reclamation of lost land is procured in the 2nd figure.

In drawing Mark 1, facts not so readily seen are—

(1) That neither erosion nor silting is possible in fig. 2, as in fig. 1.

(2) That permanency is secured in fig. 2, whilst thorough insecurity exists in fig. 1.

(3) That floods are easily dealt with in fig. 2, whereas in fig. 1 a flood spells disaster.

(4) That certain navigation for big deep draft ships is possible in fig. 2 to an extent miles beyond that possible for the shallowest drafted vessels in fig. 1.

(5) That sea entrances can nearly always be automatically and inexpensively made permanently deep enough to take the biggest ships now built or contemplated.

(6) That river water top level on the deep side is lower than such top level on the shallow side.

(7) That river entrance shoals, so dangerous to navigation, can be eliminated.

The above facts, outside of their traffic importance, mean the security of river side land property, the saving of millions of pounds a year on futile revetments and dredging, the saving of hundreds of thousands of homes, the

removal of the impoverishment of river side peasantry, and the resurrection of millions of pounds of dead money for other wealth-making purposes. Other points of importance are, that where erosion is allowed, not only is there the loss due to that cause, but the loss due to the fact that the new land in process of making in the form of shoals and new banks is idle for very many years, due to the fact that it has not yet attained a safe level, and to the fact that most mineral salts required for vegetation, except that of potash for water hyacinth, are readily floatable* in water and have been washed out of the new land (which is eroded old land) so that nothing useful will grow thereon (see chapter 12).

Rivers, which have a direction, or a resultant direction, East and West, behave in an importantly modified manner as will be explained in a further chapter.

---

* The salts required for the growth can float and exist, as explained in Chapter 7, without being in solution. They can be, and are, carried in a non-acid or an alkaline water in suspension, so that when we speak of soluble salts in suspension we mean that they are not yet dissolved, but capable of dissolution such as they must submit to when absorbed by the digestive spirit of growth.

CHAPTER II.

Erosion of River Banks

In drawing Mark 2, fig. A, we see the shape of a river bed which is made of stone. It is the result of hundreds of years of wear and tear on the off bank, but because this bank is of material strong enough to maintain its shape it but slowly wears away, and does not fall in quickly because of its ability to maintain its shape.

Water in taking a bend, because of the property of matter called inertia, which we will here refer to as the straight-on law, strikes a bend with its power combined in the form of velocity and pressure. How these two are interchangeable is shewn in Drawing Mark 4. This straight-on law pushes at the concave bank with force, but passes by the convex bank with what would be a pull if water were rigid, but which, as it happens, is nil.

Still water pressure varies as the depth. If we take a vertical strip of bank one foot wide by 30 feet depth we find that the pressure on the, top one foot has a mean of 31 lbs., but that on the whole strip there is a pressure of approximately 29 thousand pounds, of which the bottom foot provides 1,875 lbs. This means that if our bottom water moves as it does in rivers,

the cutting action of such pressure is more than anything except the hardest stone can withstand, so that it cuts the bank to an angle which leaves the top overhanging, to fall in when it can stand it no longer. The stuff that falls in, if it moves but little, is replaced by stuff from higher up, so that we are at liberty to assume that it remains in the bottom, as of course it does, to keep the now wider river at its previous sectional area. This goes on until such time as the original section of the river bed has altered from one of short base and great depth to one of long base and little depth.

Now we come to the cause of our original troubles. The area of part of a triangular section varies as the square of the depth. Let us suppose a river twenty years ago had a width of 1,000 yards and a maximum depth of 6 yards.* Its sectional area would be 3,000 square yards. The river has now eroded to 2,000 yards width, so that, to maintain its original sectional area for normal waters, its maximum depth must now be 3 yards. If we turn to fig. C, Mark 2, we see that at 6 yards depth the river can take care of 36 units of volume, whilst if we

* Throughout this book the shape of a river bed is referred to as triangular. It is of course often trapezoidal, but it is only the triangular features which are of interest to us as being variable. The central block is an unavoidable nuisance in many cases.

look again, we see that at 3 yards depth the river can take care of 9 units of volume only. Now turn to figs. B and D, Mark 2, and compare the right hand section of the top river to that of D. When a flood comes it finds the bottom of the shallow section 3 yards from the top, and that of the bottom section 6 yards from the top, with four times the capacity of the existing river. If the former overflows its banks the flood does it with all the force of its angry advance. and when it has subsided, has left the beginnings of a new river with a concave bend. This new bend has a longer radius than the old one, so that the straight-on law prefers it to its old boundary and adopts it. An examination of the shape of the river beds of Bengal shews this to be so, so that we now have a new live river, with the old one full of comparatively dead water which, because of its now reduced speed, silts up slowly and becomes unnavigable. Outside the influence of shape of Section proper we have the fact of the river bottom being 3 yards nearer the top which causes a choke, as rivers proceed on their ways chiefly in response to gravity, and head of water has in the case under review in fig. B, Mark 2, been reduced by 3 yards which is a very serious handicap for speed. The effect of speed on silt will be discussed in a later chapter.

What is shewn in fig. B, Mark 2, is no exaggeration. Bengal's rivers must have, from

ancient times, occupied hundreds of different beds and will go on doing so unless sympathetic beds are arranged at control points.

Fig. B, Mark 2, shews an allowance of 10 per cent. dead water over that in movement in fig. D, Mark 2. This would be exceeded in actual practice because the speed of water in the latter section would be always good, even at low water, whilst that in the former section would be almost nil at low water, taking on qualities comparable partly with the water of a lake.

The reclamation shewn on the right of fig. D, Mark 2, would be automatic, because when this section has been established on the left hand section of fig. B, Mark 2, the right hand sections have nothing for it but to drain in. A little consideration will shew that this is unavoidable.

It would be almost as easy to put the deep channel on the right hand side of fig. D, Mark 2, and this must be done for the desideratum effect shewn in fig. 2, Mark 1, but as the site of new river side mills would thus be made remote, the local case has been shewn and dealt with in this chapter as it will always be applicable to side streams off the main water road, and intelligent compromise is always possible. (See Chapter XII).

CHAPTER III.

THE SHAPE OF RIVER BEDS.

Rivers as water roads.

We all know that an aeroplane, a train or a cyclist when negotiating a bend has, in order to save itself, to turn its vertical line inwards from the bend. Readers who are fond of running will know that when they negotiate a bend they have to do most of the work on their off leg and, if they run on sand, they will find that their foot-prints on the off side of a bend are very deep, whilst those on the inner side are correspondingly light. A moving ship when the helm is over attempts to turn outwards to an extent which, were her equilibrium unstable, would make her turn turtle. Nothing can take a concave bend on a horizontal plane and retain its vertical poise without a very big effort. Water is blind and makes no such effort.

Readers will have seen pictures of the great motor car racing track at Brooklands and have noted the great angle of slope. They will also be aware that this angle is necessary to keep the cars on the track and prevent the centre of gravity of the car preceding the wheel grip line and turning the car over. Now turn again to figs. A & B, Mark 2, and fancy the river dried

out and used as a racing track. The angles slope in the wrong direction and a car could not proceed at all. The wheels would slip at the first movement, the car would skid to the bottom and topple over.

Now water and motor cars obey identical mass laws, and what is wrong for the one is wrong for the other. Brooklands was made possible as a car road by intelligent arrangement, and regarding river beds as water roads, equally and similarly intelligent arrangement is necessary for such water roads. All roads used by cars should be banked up upon the off side according to the speed allowed at such bends. Where this is not done the centre of gravity must precede the car, cause it to skid a bit, remove some of the off tyres and some of the off side of the road. If the road is banked sufficiently this skidding cannot occur, as the power of the car through the centre of gravity operates as a chord instead of a tangent. This is illustrated in Mark 3. Where this skidding does occur, due to the above causes, it must, and does wear the road excessively on the off side so that it goes from bad to worse.

Such is the condition of our present water roads.

The cure is as indicated in figs. C & D, Mark 2, and at Brooklands. The river at any

selected spot has shewn us the following points, *viz.* :—

(1) Its required area of section.

(2) The limiting angle the material of its bed can maintain.

(3) The width it favours for its needs for each subsection if any.

We require no further information from the river unless we desire to narrow it for a depth above which the river has not manifested an interest. Then we require to know a year's twice daily density, and temperature, direction of flow, and adjacent levels, but as this would only be needed at river mouths, the matter may be left to another chapter.

Mark 2, figs. C & D, shews this cure as an ideal. The areas shewn are, in the absence of a particular river to illustrate, 10 per cent. less than that shewn in Mark 2, fig. B. The angles shewn are haphazard, the important point being that the areas shewn are correct and that triangles on equal bases between equal parallels are equal to one another. This means that we work out our new depth by any triangle and then adapt its slope to its needs, only retaining its depth. Every river bed lends itself to this because its breadth is always at present much in excess of its needs due to the erosion previously complained of.

We now come to ways and means. In Burma, in the author's time, there were three dredgers engaged on the Twante Canal which did actually pump on a six feet draft (pump working) 12,000 tons of soil per hour at a cost of 3½ annas per 1,000 cubic feet of soil (not including water). These charges would amount to 6 annas per 1,000 cubic feet if made to include interest on capital cost, insurance, all maintenance and any other charge that could be legitimately charged against them.

Regarding operations we must remember that a river contains gigantic forces and that these forces, allowed to run wild, have caused our present situation. We have already seen how, by a trick almost, we can persuade these forces to co-operate with us, much as the proprietors of Brooklands did.

We know that water makes its major movement in response to gravity and that, as regards top levels, water always seeks a lower level which it is said to claim as its own. The idea here put forward is merely to establish hesitation points on a river as fixtures and lead the water by the desired course through a modest channel to it. The water will do the rest, not because it wants to, but because if we have placed our channels properly, it has no option. Seek a lower level it will, and if we guide it, it is our servant, and not, as at present, our master. By the above we have

sought to introduce the fact that deep dredging is not necessary along the whole pilot's course, but only at properly selected and properly manipulated points. The author hopes his view on the proper shape of a water road, and the means to obtain this desideratum, have been made clear, but he would prefer to face his reader so that he could make sure, by observation, whether any particular point has escaped elucidation. The author has much experience as an Examiner of Engineers and feels that the written word may convey a wrong or exaggerated meaning from any one to any other. He hopes that any feeling of doubt in a reader will lead him to read that which he doubts over again, and study the drawings, as he feels that a proper study of these will solve most difficulties.

Referring to Mark 2, again, this chapter will have been written in vain unless it has satisfied the reader as under, *viz.* :—

(1) That figs. A & B truly represent the shape the river water tries to make its bed in hard and soft soils respectively.

(2) That figs. C & D truly represent the shape a river bed should be.

(3) That fig. B represents a gigantic waste of land of an extent indicated in fig. D.

(4) That fig. B represents a shape which can neither deal with floods nor provide an adequate navigation depth.

(5) That fig. D provides all that fig. B lacks.

(6) That figs. A & B represent eternal erosion, whilst figs. C & D represent permanency.

(7) That the angles of figs. C & D depend upon the limiting angle the soil can maintain and that such alteration of angles, as are necessary, do not affect the sectional area if the inverted apex is kept at the same distance from the top level.

(8) That drawing Mark 3 would go far to shew why the slopes in figs. C & D are permanent.

CHAPTER IV.

Movement of River Bottom.

Drawing Mark 4, the author hopes, will almost explain itself. We have seen how the bottom of a side is eroded, but the effect of moving water on the river bed bottom responds to different laws. Move, of course, it does, but from long observation he thinks this movement is more in the nature of a leaning over, much in the same way as a tree leans from the wind. The fact of the permanency of mooring buoys, for instance, shews that bottom movement cannot be very deep, which is very rare except in the case of quicksands. The movement obviously depends upon the slope and percolation combined, as shewn in the right hand figure of Mark 4, and in extent would be but little. The true bottom must not be confused with silt which in most cases comes to rest upon the true bottom at different states of speed, density and temperature.

For convenience of statement we may liken settled river bottom movement to that of movement of liquid in a pipe. Oil is sent from oil fields to refineries through several hundred miles of pipe line and the manner of it is thus. A powerful pump at the oil fields end moves its

oil piston through its stroke and pushes say 5 gallons of oil into the pipe, in response to which 5 gallons of oil leave the pipe line at the other end, say five hundred miles away. The oil pump has pumped its 5 gallons, through the line by proxy, as it were, because the 5 gallons at the refinery entered the pipe line perhaps a day before it left it, and the 5 gallons at the pump end which caused the ejection of the refinery 5 gallons is now only a few inches in the pipe at the pump end, and will probably remain in the pipe for a day or so before it, in its turn, is ejected too.

If we knock down the end one of a row of children's nine pins the whole row will fall without perhaps shifting their bases forward at all.

So it is with river beds. To carry the simile of the oil pipe line to its logical conclusion we must reckon that the river bed moves down its slope, but, we may conclude, not quickly. It probably has a speed of very few feet per annum where bottoms are not easily percolated and slope is little. It is also subject to great pressure when it meets the sea beach line and is locally countered by an adverse head. If there had been at any time (as there must of course have been) a part of the settled river bed having a big slope, the slide would have occurred ages ago and semi-permanency now reign.

CHAPTER V.

An interesting Stocktaking of a few Important Influences on Water Movements.

Before proceeding further with the subject of waterways it would be as well if we took stock of the forces operating on them, as these forces have always operated, and will go on doing so, whether we are looking on with, or without, approval. If we grasp this fact, the need of trying to influence such forces for the betterment of our immediate wants at once strikes the imagination, and one wonders how it is possible that this important subject is in the backward condition it is. The author thinks it is chiefly due to the fact that the laws of the forces in question (having regard to their effect upon rivers) have never been properly marshalled before the world, each credited with its good deeds, or convicted of its crimes, as the case may be. It is, one supposes, indisputable that the world would not tolerate the bad deeds of these forces if it knew that with a little encouragement their good behaviour could be assured. Let us then offer to serve for the nonce, as missionaries for the conversion of heathen waters.

The first force is the negative one of this subject, being no one's business. As long as

a river's behaviour goes unrecorded, or inadequately recorded, in the file baskets of may be a dozen differently opinioned officials per each river, so long will such rivers behave as they unknowingly do, and not as they would willingly do if shewn how.

The second force is tide, the third is gravity, the fourth is bottom resistance to movement in terms of time, and the fifth is inertia.

TIDE :—As the earth swings round the sun, and the moon around us, they each exercise their own gravity forces upon us. Sometimes they work together, and sometimes at right angles, but however they work, one effect upon the waters of the world is visible in the form of spring or neap tides. This opposition of gravitational forces varies a little throughout the world, but at Greenwich, when they have been subtracted, the remainder has the power to cause an acceleration of 32·2 feet per second. The average youth can lift a bucket of water easily. A very strong man, whilst easily able to lift a bucket of earth, would perhaps pull the handles off the bucket if it were filled with lead. This difference of weight, or specific gravity as it is called, is important here, inasmuch as it explains why the non-rigid waters of the earth respond readily to tides, and the more rigid and heavier substance of the land does so only imperceptibly without a visible alteration of

shape. This unresponsiveness of the land does not mean that it does not feel the outside attraction however, because it is demonstrable that it does. What really happens is that it transmits the forces operating much as an electric cable does electricity, whilst the waters transmit it in a manner similar to the way the air transmits electric current in the wireless spark gap or the sparking plug.

All forces operating on the earth from outside sources do so in the form of waves. Waves are vibrations acting plus and minus at right angles to the plane of direction. If we take a rope, suspended at both ends, and strike it, we can see the waves ripple along its entire length, whilst the suspended ends will move in a vertical direction if free to do so. The sharper the blow the quicker the ripple. If we had a very fast cinema picture-taking machine, and, when producing the pictures, we did so slowly, we should see that our blow had caused one big wave, and that that wave had others upon it, each of which in turn had others upon it, each of which again in turn had others upon it and so on to infinity. The sun's wave is waved by the moon's wave.

This vertical motion of waves is damped by the objection of gravity, by shallowness of waters, by restriction of quantities, by choke, by angular demands from confined waters, and

by the opposition of one wave to another. We had better consider the last damper at some length.

The circumference of the earth for tidal wave purposes is, at the equator, in spring and autumn 25,000 miles to be covered in 12½ hours or at a rate of say 2,000 miles per hour. The water does not travel this distance of course, but the wave does, and the extra water for its crest development is obtained from purely local sources. A study of coastal tide tables will make this obvious. The tide circumference of the earth at Calcutta in spring and autumn is about 23,232 miles to be covered in 12½ hours, or say at a speed of 1,858 miles per hour.

The tide circumference of the earth at the English Channel in spring and autumn is 16,148 miles and wave speed 1,292 per hour.

The tide circumference of the earth at the Poles in spring and autumn is about nil, and the tide would be nil were it not for the fact that the waves impressed elsewhere vibrate to these waters.

From the above the following point stands out, *viz.*, that the exterior wave impressment upon each degree of latitude is different from each other.

Pianos have loud and soft pedals to free or damp their wire vibrations. These vibra-

tions are not really lost when damped, but they are absorbed in a manner unnoticed by the listener. Tide vibrations are damped one by each other and by every irregularity of depth and diversion. In lakes and inland seas the depth is so little, that the major wave cannot build its crest and hurries on to Westward to exhaust itself elsewhere. In rivers the superior force of gravity defeats the wave, but in all cases, such rivers, having an East and West direction, must have their speed slightly modified by the tidal influence of their own waters. In this connection we must remember that the East to West direction of a wave does not in any way mean that the water should flow from East to West. The water to build the crest does as often come from the West as from the North and South. We must also remember that if the sun and moon withdrew their tidal influences the tides would go on in a modified way for a considerable time, and that the sun and moon may be considered as subjecting us to a violent bombardment of many millions of waves per second. It is necessary to understand this in order that we can properly appreciate the reasons why waters moving in response to gravity appear to be so little affected by the tide influences at work within themselves. We must again point out that the tides as found at land approaches on any day, although res-

ponding to the influence of the moment, are still agitated by the accumulation of millions of vertical wave vibrations of the previous day which it has not yet had time enough to dissipate.

Gravity is too well understood to require further explanation. It is obviously the major influence in river water movement in its upper reaches. Every thoughtful person can imagine, as he gazes at a river in motion, the process of the water carrying out its universal function of seeking a lower level.

Bottom resistance is a great brake on running water speed and, obviously, by this cause, retards flow and maintains a greater depth than would be possible if we had a regular concrete bed.

Inertia causes delay too, as every diversion caused by it, as it bumps along cannoning from side to side in its seemingly drunken attempt to always proceed straight on in spite of all obstacles, means a loss of time in its proceeding, so that there is an accumulation behind it recognizable in a greater depth.

Other interesting influences on waterways are reserved for the next chapter.

CHAPTER VI.

Mark 3.

We have so far paid little attention to a few very important points shewn in Mark 3. Water is very different to a motor car really, but as regards its dynamical behaviour we can imagine a greater similitude than really exists, and draw conclusions which are more easily outlined this way than any other. Taking road resistance as opposed to road wear we find that in fig. 1 the road resistance to the outer wheels slightly exceeds that on the inner wheels.

Taking road resistance again as in fig. 2, we see that because the greater part of the weight of the car is on the off wheels (4 times as much as on the inner wheels, due to the vertical line through centre of gravity passing so near outer wheel ground contact), the work to be done on the outer wheel line is more than an ordinary road can stand and so it is quickly torn to ruin.

Again taking road resistance as in fig. 3, we see that because only a small part of the weight of the car is on the off wheels ($\frac{2}{7}$th of the weight, because the vertical line through the centre of gravity passes so far away from the off wheel ground contact), the work to be done on the outer wheel line is less than that to be done on the inner wheel line.

The above is of vast importance in rivers as it means a choked flow in cases similar to those in fig. B, Mark 2, and free water in cases similar to those in figs. C & D, Mark 2, because, as already shewn, the ground resistance to flow in fig. 2, Mark 3, is 14 times that in fig. 3, Mark 3, if we imagine the car road as flooded in the manner of a temporary river. The wrong section is therefore wrong from every point of view because a non-free water movement, due to its retardation, must drop the silt it carries in suspension which it picked up at a time previous to its retardation. This is fully explained in Chapter VII.

A point about which the writer has satisfied himself by experiment is this. The actual lack of balance of force as interpreted as an excess on the inner wheel line of fig. 3, Mark 3, is only existent as a potential when the car is at rest. When the car is under way its momentum negatives this excess by aiming at flying the car along the line of least resistance, by which I mean it tends to act through the centre of gravity of the car in the plane of its direction.

And so with water. The chapter on silt will shew that still water will deposit silt upon the maintenance slope of the correct river bed, making its sine with the horizontal appear less. This silt attack is unharmful and in the nature of street traffic, which is sometimes very evident,

and sometimes more evident by its absence say in the early mornings, but which leaves the street day by day much as it was before.

By the above the author wishes to impress the reader with the fact that by creating our river bed slope in the right direction, an excess of angle increasing its sine with the horizontal is not only unharmful, but right and proper, as it insures the river bank against accident for the purpose of permanency of river bed. The inertia of which we have complained so often now becomes our good friend, for instead of bearing hard on the off side it takes the weight of waters and lifts them gently to flow on in the most peaceful manner possible to water, and lightly brushes our river bed side with its silt to remove it again at its convenience, in much the same manner as we apply the plate powder to remove it again before we declare the plate clean. Study carefully fig. 3, Mark 3, imagine yourself in the car, and try and feel if the case as stated is not the correct one.

CHAPTER VII.

FLIERS, FLOATERS, SWIMMERS AND VEHICLES IN THEIR RELATIONSHIP TO SILT.

If an aeroplane or a bird gets wing trouble it has to come down because it has lost its horizontal momentum, and responds now to the only force operating, *viz.*, gravity; a balloon can maintain itself in the air when all is well, but, when due to any cause its weight exceeds the weight of the air it can displace, it too falls. If we expand the balloon envelope by more gas it will rise again. The average cyclist cannot balance a still bicycle, but he can do so at very little speed if he is well practised.

The above points are put before you to shew that the forces which enable total or partial suspension in the air are relative horizontal momentum and buoyancy. Either will do what we require of them under suitable conditions, but either will fail us if the conditions we provide are unsuitable to them.

There is a good deal of confusion of thought about matters in suspension in water, and the writer has had no little difficulty in persuading certain hearers of the fact that salt and silt exist independent of each other, the former being in combination with the water as a mechanical

mixture, whilst the latter is only in the water as a stranger, sometimes floating, sometimes flying, and sometimes meandering along the bottom. Silt in no way affects density. The sea is just as salt when dirty as clean, and the river is just its own density at any particular spot, quite irrespective of the amount of stuff seen to be in suspension. The quantity of silt in suspension however is much affected by density, which is a very different thing.

Silt in water is merely a vehicle or vessel, and behaves in that medium in exactly the same way as birds behave in theirs. The other influences of density and temperature certainly affect silt as much as a balloon is affected by the temperature of the air and by the barometer, but although we must consider these influences and appraise their values and occasions rightly, we shall find that they can be treated as influences only, and not as major causes.

Turning to Mark 5, we see the positions in which the same salinometer will float at different states of density and temperature. The writer feels sure that these varying positions of flotation are not generally realized, and that if each water as shewn were now given a movement usual to rivers, it would be found that the case where the salinometer floated highest would be the case where silt would float on the surface and be most of it in suspension, whilst in the

case where the salinometer floated lowest we should find that this inclination shared by the silt took the form of deposit.

The above is overwhelmingly important in a case similar to that of fig. B, Mark 2, and negligible in cases similar to those of figs. C & D, Mark 2, because in the latter cases speed of movement sufficient to maintain suspension is assured, whilst in the former case sluggishness and deposit are bound to happen.

We may conclude, therefore, that when a river water is moving as is the usual case, and subject to the effect of density and temperature as indicated in drawing Mark 5, such silt as may be moving may be considered as an inexperienced swimmer such as would be likely to sink when movement ceased.

We have in this chapter considered the case of fliers, floaters and swimmers, and we must now turn our attention to the last case of the vehicle which is carried more or less upon the bottom.

A glance at Mark 4, fig. 3, will shew, in the light of what has gone before, that given sufficient speed the top slice could carry a great proportion of silt, the next slice less, the next less, and the speed at the bottom will be so little that the silt must of necessity crawl or ride along the bottom. It will be found in cases where there is a halt due to reversal of tide, that, as the speed

picks up again in its new direction, it so little affects the bottom that the swimmers shew no inclination to leave their bed and they sleep snugly in the bottom with the vehicles. Should one stir the bottom water, these swimmers would perforce leave their bed and, having again arrived at a sufficient speed slice, would remain suspended therein until such time as the speed has again dropped to enable them to continue the slumber we so rudely interrupted. Such an interruption generally takes the form of an abrupt alteration of river bottom level, brought about by a step or a rock, and would always behave the same way subject, of course, as before said, to moderation by temperature and density.

If now we turn to Mark 1, and Mark 3, and think what happens when one river pays tribute to another, we shall see that there must always be, in the case of all such meetings, a scrimmage between the slice levels, as each makes each give up part of each other's momentum. If the one river is proceeding over a bed whose angle of slope is different to that of the other, and whose bed bottom is at a different distance from the ground level, these scrimmages must be sufficient to stir up every ounce of crawler vehicles and turn them into bad swimmers such as will probably take the first opportunity, when they have swum to a more restful situation, of reverting to their characteristic slumber as silt and shoal.

The author is here anxious to again remind the reader that silt cannot affect density, but that density can and does affect silt very much. Water does not get saturated with salt at temperatures to which the sun submits it, when it gets circulation, but, of course, this does not apply to choked and shut-off salt pans or salt lakes where evaporation exceeds fresh water supply (either by design or nature), so that, although we may not ordinarily delete temperature as a factor in silt-carrying saline waters, we may relegate it to a minor position which we cannot quite afford to do when dealing with fresh water capacities for silt. The amount of salt in a gallon of sea water is five ounces, which as a silt supporter is enormous, as it can support at all temperatures usual to such waters its own weight displacement of silt without reference to temperature and speed, which are the major forces keeping silt in suspension in cases of fresh water. To find a natural ready-made proof of this intrigued the author for some years, but his persistent search for the site of the toe of the salt wedge Mark 7, shewed him clearly that the peculiarity of clean sand beyond the toe filthy sand within the wedge, and clean sand out at sea bears this point out, as he has satisfied himself that the sand is, in each case, similar, and that the dirt upon it is due to the fact of varying degrees of suspension power in the wedge

which does not exist beyond it, whether in the sea or fresh water. It is worth noticing in this connection that at sea and well up a river, you may have a filthy looking water with a clean bottom, but that within the salt wedge you could have, but rarely visible, a clean top water with a filthy bottom.

The above means practically that with water of unaltering density such as found at sea and in the upper reaches of a river, silt is carried consistently, being only subject to alterations of speed in the first case, and of speed and temperature in the latter. That this is so the writer is confident, as a number of experiments have confirmed this belief. That such alteration of speed is serious at times any aeroplane pilot with engine trouble can affirm, and our friend the balloonist will tell us of the effect of a cold breeze upon his altitude records. The latter, if flying low, may be made to land as surely as the former, but such alterations of speed and temperature can be provided against, and are not of the nature of things likely to embarrass us much in the stouter medium of water. We may not however feel so easy about the things that happen in that stretch of water where it has the density of sea water at one end, and the density of fresh water at the other, but it will be best to leave this chapter here, and devote a separate one to the doings of the salt wedge.

CHAPTER VIII.

MARK 5.

A most Interesting and Important Chapter.

That the salt wedge really exists, the author feels he can prove, but he also feels that it may be a little difficult for the reader to imagine its definite boundaries, and that it works so much like an exterior view of an old-fashioned bellows. Its slope may be a little irregular, but in the main must be substantially as shewn in Mark 7. The difficulty of recognition lies in the fact that, although the line of final loss of density, which must stretch almost straight from heel to toe of the salt wedge, could be definitely shewn by sufficiently delicate instruments, such instruments are not used by those who may be most nearly said to hold functional offices from whence may one day emanate those measures of river control so urgently suggested. In the absence of these delicate instruments it will be as well to use those at present sold by instrument makers, and deduce from our observations and records with these the only possible conclusions tenable. Let us keep Marks 5 and 7 before us whilst the author tells of his experiences bearing on this chapter. He lived in a bungalow on the river bank and was responsible that no ship entered or left

the Port overloaded. Readers will be aware that big ships sink several hundred tons of capacity in fresh water, and as the Rangoon River was variously said to be salt and fresh and many sailors had opposing views on the subject, it was necessary that he placed himself in a position of undoubted authority. With the above end in view he procured an hydrometer, and had the beginnings made, of what he hoped would be a reliable record of the river's density from day to day, but he soon found that his methods were too crude to deal successfully with vessels, some having drafts of 28 feet, and others perhaps of only 12 feet, as it was obvious that the former vessel might be largely immersed in salt water, whilst the latter may be wholly immersed in fresh water on the same tide and same place on the same day. Other methods had to be devised, and satisfaction of a sort was attained by the equipment shewn in Mark 5. His records were taken daily at 10-0 A. M. over a period of 3 years, and were kept in his diary, whilst the site was off the pontoon at the bottom of his garden, so that there was little chance of the matter escaping constant attention, and only did so on the rare occasions of his absence.

Mark 5 shews how temperature affects salinometer reading, so that a temperature correction is always necessary. The author first of all used to make these corrections by calculation,

but ultimately adopted the plan of drawing off a quantity of drinking water, and leaving a similar pot of each water in the same room for a few hours to obtain the same temperature. The weight of a cubic foot of fresh water is 1,000 ounces, whilst that of sea water is 1,025 ounces, and the entire three inches of special salinometer stem is devoted to degrees between these extremes. The true weight of a cubic foot of the water we wish to measure (properly and indubitably corrected for temperature) is 1,000 ounces plus salinometer reading of the water under test, minus the salinometer reading from the fresh water. It is noteworthy here that the water under test is probably dirty, but that, as explained in the previous chapter, in no way affects density, any more than putting a boat upon the water or a few fish in the water would do.

The method of obtaining true bottom water for measurement gave considerable trouble at first. The desideratum was that the water should be taken at the same place each time, by which is meant a spot holding constancy in the matter of its position in the curve of sweep of flow, both as regards its distance from the bank and from the bottom. To get bottom water unaffected by top water was not as easy as it looked, so that the author had to devise the pot shewn in fig. 5, which always gave satisfaction and reliable water. The operation of the pot is

obviously easy, but some men never became successful manipulators, so that a description will not be out of place here.

The pot is first emptied and dried, and the lid placed in position and carefully sealed with tallow. The pot is now inverted and lowered into the water until the feel of the lowering tackle lets one know that the lead weight has reached bottom. The pot is then reverted by the hoisting tackle and the lid lanyard pulled to release the lid. The air contained now bubbles to the top, its place being taken by the water found at our predetermined depth and position. Care has to be taken that the pot is not lowered on to the very bottom and that it is hoisted, by the tackle provided, in a steady manner, as it is possible to partly spill the bottom water and get it replaced by upper water unseen, as the pot is being lifted.

If this operation has been carefully performed we can rely upon obtaining what we set out to get. The business requires appreciative handling for reliable results, and no departure from the routine laid down. The author has known of a whole week's records being lost, because a defect in the lowering tackle was considered to warrant lowering the pot by the hoisting tackle, with the result that the contained air in the pot in asserting its buoyant qualities on the lid instead of on the bottom as

arranged, lifted the lid sufficiently to allow the air to escape, and at the same time allowed water of an undesired depth to fill the pot.

It will be obvious that the pot when filled under water can, subject to non-spilling by careful handling, be drawn through other water without in any way partaking of the qualities of such other water either by the process of absorption or emanation. It is of course understood that the time required to hoist this pot is not to be unduly delayed, as an exchange of character can and does occur slowly, but, it is urged, so slowly, that it can be regarded as negligible in ordinary circumstances attending the obtaining of our water specimen.

It is perhaps as well to point out here that the precautions taken are necessary for correct information and proper conclusions, as the matter has been so casually treated, in my experience, as to be the direct cause of traemendous amount of misery, poverty, and the feeling of public insecurity which must always accompany doubt as to permanency of ownership of land.

Two other points which appertain to this chapter but require no further elaboration are :—

(*a*) The author's salinometer is reliably graduated to show a density of one sixteen thousandth.

(*b*) The temperature correction for density is not required in the case of ships, as the ship

and the river are affected in the same manner on the same day. It is of course understood that yesterday's record, in spite of its great value for river investigation, is not a reliable thing to use for to-day's ship.

CHAPTER IX.

THE SALT WEDGE.

Chapter VIII shews the methods employed to obtain an accurate record of the density of river bottom water. The records shew that the popular idea of a block of water moving up and down the river through the river entrance has to be very considerably modified, because they shew that the density of bottom water is almost constant between one tide and the next, but that it varies between seasons. The bottom water of the Rangoon river varied in density in the author's time never as much as ·001 per day, but touched, for a very few days only, the extremes of ·026 and ·003. For nearly half the year the density was ·021.

The impression left on the writer's mind is, that the bottom water close to a river's mouth does not, under ordinary circumstances, move much in a horizontal direction in response to tide, but that it does, slowly and almost imperceptibly, move in a horizontal direction in response to season.

The author's duties regarding prevention of overloading clashed with his duties as an Examiner of Engineers; office routine had to be

carried out chiefly before office hours, by which he tries to impress the reader with the fact that his harbour tour chiefly occurred irrespective of tide. Some ships were in port about a fortnight, some were emptied and cleaned and opened up for his inspection, and some were fretfully unloading and reloading, but whatever their condition, their load line discs on the ship's side were always of considerable interest to him, and led him to the habit of speculating the amount of freeboard which he would find when he repassed any particular ship on his return journey, perhaps two hours later. The allotment and approval of, position of the load line discs of sea going vessels is an important part of an Engineer and Ship Surveyor's duties, so that, seeing a vessel about to complete her loading at the expense of, say, a 100 tons barge, and finding the ship had more space at the finish than at the start, was bothering to say the least of it. Knowing the habits of second engineers with bilges and tanks, he was inclined to blame them, but finding that a whole line of ships were shewing identical symptoms, he was forced to conclude that there had been an alteration in carrying capacity, or density, of the water in which they rode.

Now the position is this. We have proof that, to all intents and purposes, bottom water per short period is constant. Our eyes and salinometer tell us that top water per the same

period is not constant, but that it behaves in such a manner that, when on the ebb, the water can carry its ship increasingly high out of the water, whilst on the flood it carries its ship decreasingly high out of the water. When one realizes that quite a usual fresh water allowance is 6 inches, and that such a ship could carry about 60 tons per one inch at this draft, readers will realize the importance of correct information on this point both to those who are ship-owners and to the public who ultimately pay their freights. The difference becomes less as one approaches the actual sea and more as one recedes from it.

Now turn to Mark 7. It will be seen that our observations are consistent with the assumption of the salt wedge as shewn in every particular. If we take a point partway between the top of the heel and the toe we see how a deeply drafted moored ship must sometimes be borne on a water of an alarmingly different density (from the freight carrying point of view) to that of a few hours before and after. The movement of the toe of the wedge does not affect us very much from this point of view.

The definite acceptance of the salt wedge theory at the sea entrance to inland waters is, the writer thinks, essential to proper control of those waters. It would seem to be only a

thoroughly regrettable circumstance if those who, in the absence of a recognized water control authority, have burial control of water control ideas, should have no ideas about the subject at all, but the circumstances as mentioned above becomes wholly mischievous when, as must sometimes happen, responsibility is possibly unintentionally evaded in emergency cases, by calling for, and acting upon, the opinion of men inadequately trained and experienced to give an opinion upon this great subject about which, if improperly understood, they can only be right by accident. The writer thinks that many million pounds per year go into inland waters in one form and another, and feels that the trouble does not end with the impoverishment of the funds used, but crops up again generally further down the river in the form of the navigation deterrent, known as a mud bank or shoal.

Let us take another view of the matter to prove the existence of the salt wedge. Here is a portion of a river 40 miles long by half a mile mean breadth and $\frac{1}{200}$th part of a mile mean depth at top of flood. The mean low water is in the morning when the mean depth has fallen to $\frac{1}{400}$ th part of a mile. At bottom of ebb there is therefore $\frac{40}{1}\times\frac{1}{2}\times\frac{1}{400}=\frac{20}{400}$ of a cubic mile=7,359,897,600 cubic feet of water in the portion of the river under discussion. At the top of the flood in the afternoon there

will be twice this amount or, say, for easy reference, 15 billion cubic feet of water, a difference between ebb and flood of say $7\frac{1}{2}$ billion cubic feet.

Now let us go to the river mouth and take a suitable position and pitch our camp for a few hours. The tide commences to flood in the morning and proceeds at a mean surface speed of say the great speed of 6 miles per hour until the top of the flood in the afternoon.

The quantity of water which has passed us by in the approximately 6 hours needed for tide assertion will therefore be, if we refer to Mark 4 again, (mean speed between half depth and full depth will be that of the $\frac{3}{4}$ depth slice) $\frac{6}{1} \times \frac{9}{2} \times \frac{1}{400} \times \frac{1}{2} = \frac{13.5}{400}$th of a cubic mile. On a 40 miles stretch of parallel banked river we have therefore indicated that $\frac{6\frac{1}{2}}{400}$ ths of a cubic mile is present at top of flood without having entered the river mouth. This 2·4 billion cubic feet would be about right in practice on a 40-mile stretch under the conditions indicated, because the usually gaping river mouth would be beyond our point of measurement, and for the purpose of supply would be, in effect, a sea bay at the mouth of our river. The author has seen ships swing to the flood at Busra which is up a very narrow river, and is something in the vicinity of 100 miles from Fao

outer bar (not Fao). A sailor told me he had seen a ship now and again swing to the flood at Bagdad which is perhaps about 600 miles from the Fao outter bar.

Another point of view which requires recognition of the salt wedge is the fact that, under the conditions familiar to us all in our rivers, it is impossible to conceive a line of abrupt demarkation between our familiar salt water and our familiar fresh water, because salt water does not convey salt under usual river conditions in a state of saturation. How often has one asked the question, after sipping once unsweetened tea, "Have you put sugar in my tea"? and heard the reply "I don't know. Stir it and find out." This matter of stirring affects every river and it is difficult to compare any particular couple. The author can find, by experiment, no useful information as regards the rate of acquiring and losing density, except that each river, by local usage and conditions, establishes its own rate and can be dealt with accordingly. Accurate records are essential to perfection, but as ideal conditions are never obtainable because of varying tides and temperatures, this point can, generally speaking, be left to short period observations. At the same time the recognition of the fact that stirring can cause mixing, and that sugar and salt can remain as such in water for a long time, unless violently agitated,

must also tend to shew that the salt wedge referred to must be considered as embroidered on its fresh water contact slope with a line of infinitesimally brined water and that such must be the true interpretation of the top boundary of an otherwise unidentifiable salt water wedge at a river's mouth.

The time of high water is later up the river than near the mouth because water uses wedge influences to shew itself up the river. Drop a piece of white paper into the flooding water and watch it proceed at a good proportion of the tide rate up the river and then ask an intelligent and experienced inland master what time the paper will arrive at the end of the up river tidal influence. He will tell you "never," which is quite right, because, although maximum depths will shew themselves up the river a few hours after they have shewn themselves at the mouth, the movement of our paper will have been but a small portion of the distance between these points. Another point we must remember is that high water up the river will at some point coincide with low water at the mouth. More surprising too, it can be ascertained that low water can coincide with high water up a river, low water higher up and high water still higher up. There seems to be no reason for this other than the salt wedge which is the conveyor of the major perpendicular motion of the sea.

A study of the author's idea is to be found in Mark 8. If the salt wedge of Mark 7 is accepted, the fresh water waves, as illustrated in Mark 8, must be a certainty. If we can agree about this, then all doubt as to river forces vanish, because the times of high and low water along the whole bank establish every detail of every wave, and the rest is easy. Ground and bend resistance in terms of time and proved strength of soil are all exposed, and any river project can be tackled on pure premises.

Comment on a river's own inate tidal development has not been made in this chapter as everything that happens in such a river is exposed by irregularities in the plotted wave vibration, time and slope as shewn in Mark 8.

A proper and adequate time survey of a river is all that is necessary to shew conclusively the different behaviour of a river flowing in any direction from that of another flowing in any other direction.

The salt wedge may be considered, at its heel, a river toll gate, with bottom hinges, almost inasmuch as when its heel is lowering it allows a certain amount of the partially salted water above it to flow out, but when the heel is rising, it shuts off this exit and carries on with its business of impressing the sea's tidal will upon the river to the extent that the choke, superior height, soil peculiarities, and direction, will permit.

The effect of a river's position in its watershed requires no comment. A few years' records are desirable, but all that a rainfall can do is already written large over the river and its bed, as we find it.

Referring to mixing again, it will be obvious that if a confluence happens within the wedge there will be a great mixing and the presence of salt made obvious at the cost of shortening the wedge base. The ebb tide is always able to take away this mixture at a greater pace than mixing can produce it.

CHAPTER X.

THE SEA APPROACH.

The Sea Beach Habit of the Sea.

If the source of a river is important at its birth the sea approach is quite as important in its function as controller of its destinies. I one examines the shape of a sea beach and thinks how universally the same beach laws are to be found; if one realizes the vastness of the sea approach compared to the threadlike nature of the rivers which are said, in a sense, to empty into it; and if we accept the salt wedge idea, there is nothing for it but to give this sea approach all the attention it requires if we desire the river to behave in a manner satisfactory from our point of view.

The sea beach in a true sea bay, that is, one which uses only its inlet for its outlet, is always shaped in a manner similar to that of a rim of a plate and quite often as that of a rim of a soup plate in its relation to the central bottom. This sea beach habit of the sea is so confirmed that a river interrupts it but little, so that we must expect to find, as we always do find, that the beach attempts at all times to place itself across a river's mouth and that it does so in its non-broken water surface aspect always, unless actively interfered with by natural or artificial

means. If we examine the river entrance as shewn at Mark 6, we must conclude that the shoal there shewn is the beach effort breached weakly, without much depth on either side of the shoal in the breaches. A fresh study of Mark 2 will shew how the ordinary laws of flow of water will be affected by the situation and lead us on from bad to worse.

The author had made many efforts to gauge the amount of water passing certain points in a river in measured times. Retardation and fall have their usual familiar effects, but when the so called river mouth is reached all is chaos. A confluence is in many cases similar to a river mouth within the meaning of this chapter (see Mark 1) in so far as chaotic conditions prevail.

Now the sea beach habit of the sea is a very serious and real thing to breach, and to do it permanently and cheaply we must help the river all we can. The best way in most cases will be to haul the river back to the bed from which it has eroded itself, so dimension its mouth that there will be a minimum of dead water at change of tide and so arrange our bed section sides that, as shewn in Marks 2 and 3, the straight-on force will be made futile and the off side be kept clean and free from silting. Our depth will be the maximum, the force opposed to the sea beach habit of the sea will be a maximum, and the river mouth will be a permanency.

Suppose the sea beach habit of the sea exercises a pressure of only 1,000 tons per foot of width of river mouth, and that our river mouth is only 6 times as much as it should be. The colossal forces to be overcome by the dissipated river forces are then seen to be thoroughly impracticable and shoaling occurs *ad lib.* to the confusion of navigation, safety of life at sea, the shallowing of our rivers, the handicap of commerce and an adverse influence on the number and shape of vessels required for inland water traffic.

The sea beach habit of the sea, like the good workman it is, uses the tools it finds ready to hand. Amongst these the chief is the wonderfully valuable land which, through avoidable erosion of river banks, has been allowed to topple into the river and float, or swim, or crawl, down to the sea beach site.

The author believes it can be proved that Bagdad, now about 500 miles from the Persian Gulf, was once upon that Gulf. Travelling through the Inland Waters of Bengal, it is hard not to believe that the greater part of Bengal is new, made by the sea beach habit of the sea, at the expense of most valuable ground avoidably eroded from elsewhere.

The effect of the shape and size of a river entrance is seen in a hundred different ways. For instance, when the sea is above the shoal

shewn in figs. 1 and 2 of Mark 6, the ebb makes over about nearly 3 times the area of fig. 3, at of course about $\frac{1}{3}$rd the speed, which helps the sea beach habit immensely. If there were two big shoals speed would drop to about $\frac{1}{5}$th, if three shoals to $\frac{1}{7}$th, and so on. Much more water than indicated by these speeds would be present, but the point is, that the quantity of silt produced by the eroded banks is spread out amongst these waters, so that the speed of deposit for making the sea beach is to all intents and purposes as stated.

Another effect of a wide river mouth is that the shoals by creeping up and choking what should be the true river, penetrate the top of the falling tide level, which means that the water on the river side of the shoal is detained, having no easy road of egress as it is on the same level as the side water. It is true it presses slightly, but obviously not at as great a pressure as existed a moment before, so that a temporary halt is called behind the shoal, an ideal set of depositing conditions. Again on a rising tide, the water as it creeps over the top of the shoal finds its area increased from that of the two sides of the river. Again a temporary halt is called and the inclination to deposit materializes in an accumulative manner behind the shoal, because the slice level on the sides is many feet up with suitable non-deposit velocity, whilst after the first rush

the top of the shoal is of course the bottom of the water which will, obviously, according to Mark 4, capture as much silt as it can to add to our troubles. A good proportion of the silt accumulated by the agency of the shoal must of course fall down the natural angle of the shoal-slope, to raise the river bottom to interfere with navigation.

The importance of the previous paragraph lies in its influence on the negation of wrongful dredging. For instance the silt deposit and the beach habit with the existing width have established a natural level of bottom which they easily maintain, although they are only slowly able to increase the deposit which decreases the depth of water available for shipping. A dredger now comes into operation and attacks the bed attempting to create an unnatural channel. The beach habit and silt deposit between them can defeat this with ease, as the dredger is in no way attacking the cause of the shoaling.

The use of the words natural and unnatural are advisable because they indicate the cure of the situation. What is required is to arrange our river mouth area of section so that its bottom will, of its own volition, adopt that depth we desire. If one thinks about this at all one must see that any attempt to establish an artificial depth calls into action all the forces that can oppose it.

It would almost seem from the above that the author deprecates the use of dredgers altogether. This is far from being the case however, because he knows how very useful they are to help out a difficult situation by creating any two properly proportioned points for the river forces to exercise themselves, to their final correction, between.

The object of this chapter is to shew that one of the great needs of a river is to make sure that its true mouth is so proportioned as to be able to maintain permanently, without further aid, its, to us, satisfactory depth by virtue of its own forces.

How to do this should now be obvious. It is, in a number of cases, best done by dredging the mouth to a section and position as shewn in Mark 6, and allowing or contriving the other entrance or entrances to be blocked up. In bad cases where the soil proved to be unstable by virtue of its nature the preliminary forcing could be reinforced by a stone revetment.

The author also hopes he has left the reader with the impression that dredging a bottom at any part of a waterway is making an unnatural alteration of section and that we must always, where we dredge, alter the bed banks so that our final sectional remains as before, that is, of the section that the river has declared and proved to be its need.

CHAPTER XI.

CANALS AND OTHER WATERWAY CONNECTIONS.

When two main waterways are connected by a natural creek of long standing it is obvious that it will have confirmed all its habits and be a good or bad water road accordingly. If then we devote this chapter to artificial waterways projected we shall at the same time be covering most of the ground that can be of any influence or use in correcting defects in existing ways natural and artificial.

In projecting a new canal and having decided upon the width and depth required, the chief points to ascertain will be—

(1) The difference of mean level reigning at each end.

(2) The rate of flow at each end.

(3) The difference of time of high and low water at each end.

(4) The difference of immediate bottom level at each end.

(5) Width and depth of receiving ends along the line of the axis of the canal, or the natural volume capacity at each end.

Regarding (1), (2) and (3) this information is required to ascertain if the water of the canal can be partially changed each day. If it cannot, then it will silt up and soon become a failure from the water road point of view. If it can change a little water each day in one direction, it means that in a week or so the whole of the water of the canal will have been changed, and all will be well.

Regarding (4), the difference of the bottom level at each end can be adjusted by building a weir at each end, and it is probable that by arranging these weirs properly that defects in Nos. (1), (2) and (3) could be corrected.

Regarding (5), the width and depth of the connecting ends must be sufficient to take or give the canals contribution without unduly interfering with the ability of either end to cater for its own needs. For instance it is almost useless to have a gradient if at the bottom the river is too narrow, not deep enough, or too sluggish to be able to accept gravities contribution without choke. Similarly if at the top of the gradient the supply cannot meet the demand further trouble will ensue down the robbed river.

From the above it will be seen that a great deal of attention is necessary if we are to have a new canal scheme turn out successfully. If the canal runs latitudinally, and sufficient depth

of water is available in the Eastern connection to give a tide vibration its needed vertical depth volume, there will surely be a tide in such canal acting quite independently of the movements of the waters of its, perhaps, longitudinal connections, which are probably responding to the tidal vibrations impressed upon them by the salt wedge in a manner as shewn in drawing Mark 8. If the two rivers to be connected go through tortuous beds of different length, it is more than probable that there may be high tide at one end of the canal with low water at the other. This may beget a bore or may not, and will be more effective at one time than at another. It should be easily possible to satisfy oneself about this before settling the true direction of the canal by a study of the tide tables of the world along the mean latitude of its bed, as by a correct interpretation of the time of greatest local pull, a comparison could be made between the three then known times of high and low water.

The question of new canals is more interesting than that of existing waterways because the latter have exposed their hands whilst the unconstructed canal may defeat us entirely, unless we go very carefully indeed into all the information we can collect. We should consider a canal of short length as not as good as it could be made if constant dredging were required to keep it open for heavy traffic.

And then too, in designing a new canal we should consider how we are to enable it to keep itself clean. It should, of itself, carry its own sweeper's broom. and this can only be done by constructing the canal bed of a section only slightly modified from that shewn in fig. C, Mark 2. It should be slightly sinuous along its length, to prevent vibration dying of exhaustion, for, by forcing them to cannon harmlessly off our properly shaped bed sides so that the water, by virtue of its inertia, will bump merrily along from side to side, they will clean up all that slack water and the traffic have left behind. It appears to the author that the sweeper's broom idea demands a little sinuosity in the construction of a canal, for much the same reason that one doesn't push a broom across a room to sweep it, but always give it a frequency of short sharp pushes to attain that object.

CHAPTER XII.

RUMINATIONS.

In Chapter I we said that new land was idle for many years, due to the fact that most mineral salts, except that of potash for water hyacinth, are readily floatable in water, and have been washed out of the new land (which is eroded old land), so that nothing useful will grow thereon. This washing out of salts is a terrible disaster to land, animals, and all that grows on land, but a god-send to fish, so that we may congratulate ourselves that the salts are not lost because we know where they are.

America was once, in parts, a great forest through which millions of animals roamed or drew their necessities. Now if we realize that a big tree, in full foliage, constitutes a roof (which leaks like an ideal watering can) of many feet depth over the entire area occupied by its roots, we shall see how very self-supporting a tree is to itself by providing its own manure and conserving all the salts that belong to it ; besides which it is able to support a big family of other minor and major growths, each greedily absorbing excesses provided by the big tree, to change them in turn into a form more palatable to the big tree, which in its turn grows bigger and can support a bigger family.

The above is very important, because this family of major and minor growths consists of that which, like all other things, follows the line of least resistance to absorbing instinct. What is meant is that the absorbing instinct of the tree is to grow, and if any alteration of condition of site occurs it will alter the nature of the tree (or of the other growths which depend upon its shade), and in a season make an appreciable effect upon the tree's appearance and prospects. If the major and minor growths are, as they were in America, human, animal, and vegetable, and the lumber man cuts down a few thousand square miles of trees with their continuous roof, the rain comes and those salts, which the expired trees found so readily absorbable in their saps, are floatable in the rain water too, and are carried off in the usual manner to the rivers and the sea, so that our major and minor growths have now to exist upon a soil as innocent of useful growth possibilities as a sea beach is.

Another point which will have struck us all is, that the tree roof by maintaining its tiles apart, has shewn an enormous capacity for holding the greater part of a rain-storm on its own leaves. It also has a tremendous area of surface for evaporation, which every one familiar with the cooling effects of the latent heat of evaporation will realize, means that the earth beneath the tree roof is not only protected from rain and sun

but is provided with a refrigerant roof for the day and a warming roof for the night. The different specific heats of land and saps explain a lot of this.

The cutting down of trees then means that the land which should, in our best interests, be protected from excess of rain and sun, is now without protection and is denuded of all that distinguishes it from the waste parts of the earth. The rain washes the needed salts away, and the ground which nature in its wisdom, and of itself, has shewn to require not only shade but a cooling medium, is left exposed to the killing effects of the midday sun and the equally deathly effects of that coldness which reaches all that is unprotected at the approach of dawn. The author has seen photographs of vast expanses of America's one time dense jungle and forest, now as bald as the Sahara.

Chinese history indicates that the government of great parts of that country was for a long time unofficially administered largely by the carpenters' guilds. China is supplying very many thousands of carpenters now to other parts of the world because of her internal timber shortage, and famine stalks China as a direct result of the removal of the forest umbrella from off her soluble salt reserves.

From the above it will be seen that the author views the loss of soluble salt from a land as wholly

mischievous. Its recovery is tedious and expensive and of course only ever possibly a small percentage of the quantity lost. Its partial natural recovery comes about in the following way.

The river has risen, it has flooded, it has fallen, it has madly eroded as much bank as it can, it has shoaled the eroded quantities lower down but almost innocent of growth salts (except water hyacinth), and now proceeds to rise again. It is full of growth salts in solution which it, subject to the fish toll, maintains quite easily. Now if the diagram Mark 4, illustrating bottom movement, has been followed, it will be seen that at the flood slice level, the water which covers the semi-new land becomes bottom water to that very little which is above it, so that it comes to a halt and deposits its salts upon the before almost saltless land. A few shrubs will grow on this and afford a measure of protection, besides slightly (by virtue of their roots) raising the land a little more, so that next year's flood will find the land much better able to accept and hold soluble salt deposits. Thus and thus until the new land becomes like that so familiar to us in Bengal, a land with perhaps one per cent. of its possibilities on the land and the other 99 per cent. useless, more or less, in the water.

The situation is ridiculous outside its aspect of tragedy and general poverty and misery.

Reference has been made in a previous chapter to the idea that Bagdad was once upon the sea of the Persian Gulf. Now rain can only come from a condensation of the aqueous vapour brought about by a quiet evaporation of the wet surfaces of the earth, whether they be oceans, lakes, rivers, or vegetation. Sir William Willcox hoped to put 18 million acres of unproductive land under water in Mesopotamia by choking a few wet outlets, but in the meantime these and many million other acres are dry where once all was wet. This means not only that the country North of Bagdad loses the services of the rain provoking areas of Mesopotamia but has to share, with that saltless and therefore incompetent area, the rainfall which it itself provokes in addition to the now curtailed rain producing area, the Persian Gulf. Similarly with Bengal in many ways except that her districts have a population which by virtue of their residence, habits and agricultural methods of bunds, do make some little effort to conserve what little they have. The matter of erosions of river banks however is very serious in Bengal, especially with regard to the Megna, and some very big uncasual effort is needed to put this matter right. The author thinks the necessary suggestion has already been indicated, but it will be more fully detailed in the next chapter.

Regarding Chapters V and IX, it is worth connecting them here by a few further remarks about the behaviour of water.

Chapter V and Mark 5 both shew that hot water carries its burdens lower than cold water and that salt water carries its burdens higher than fresh water. The Marine Survey of India dredge the ocean's bottom occasionally and find the most surprising things, but the one of most interest to us here is the fact that the water at the bottom is, under normal conditions, many degrees colder than that at the top. Turning to Mark 7 and Chapter IX, we find greater density and lesser temperature at the bottom of the wedge than at the top, so we may assume that silt is carried higher in the wedge than out of it, because of lower temperature and greater density. This would be at once evident on the slightest movement.

Referring back again to the end of Chapter II, the possibility of intelligent compromise is mentioned. We should plant the section shewn in fig. D, Mark 2, on the right instead of the left, but, if we do so, we shall often find that the people who have made a noble attempt to check erosion and to keep what they hold by revetment will find, say their mills, a mile or so inland when the drain to the right hand section begins. Further the right hand sections by silting up have been collecting most valuable soluble salts

(not sea salts of course) for perhaps a few years, so that it would be a pity to empty such an accumulation into the depths of a new channel again.

The author's wish regarding Mark 2 is to leave the impression that although the section shewn in fig. D must be on the right for the desideratum of Mark 1, it will be frequently possible and desirable to put it as shewn (for the sufficient reasons given) in the many side streams, such an one for instance as is shewn as the left tributary of fig. 2, Mark 1.

In Chapter V the earth is assumed for the purpose of our argument to be on an upstanding axis in spring and autumn. It is also loosely suggested that the moon then goes around the geographical equator. This is not of course strictly so, but for our purpose is a legitimate premise.

The author has to do with ship construction, and has to criticise and pass, or refuse plans for all sorts and conditions of craft designed to carry passengers, and although matters of cost are, strictly speaking, outside his business, the question of costs does obtrude itself. The cost of an inland steam vessel is about four times that of her infinitely superior sister which goes to sea, although she carries comparatively little cargo. Deep sea vessels are built of fine material and comply with very wise rules. Inland vessels are little stronger than big iron baths would be,

and have no real rules of construction except that of the Surveyor's satisfaction, and would, if unstrengthened, break in two in a sea swell. The cost of inland navigation traffic is therefore unduly high, the cause again being "Erosion of River Banks," which by allowing the banks to fall in cause the shallows which compel designers to build freak vessels to negotiate such shallows.

Looking again at fig. B Mark 2, it will require little imagination to see the possibilities of this unnaturally large area of unscavengered water adversely affecting the public health. The population drink this sluggish dirty water in which so much cholera and malaria has its origin.

Just now Europe, India and the rest of the world are in political chaos. Quasi-political strikes and communal sulkiness will seem to a lot of us to spell just the one word "Neural." The situation would seem to be chiefly in the hands of unqualified dentists, but we may agree that the social doctor could do more for us although perhaps for a greater fee. The thought of how we can help to cure ourselves arises, and the author ventures to suggest that secure tenure of the land would, certainly in Bengal, go far to alleviate the pain. He has studied existing and ancient charts and is astounded to find how Bengal has submitted to have the major portion of its land sway, in pendulum manner

between river bottom and new land. The situation is absurd and has only been defeated by a few Britishers, like jute mill owners, who have practised the motto "What we have we hold." If Bengal could become optimistic about land values she would smile again, and the author hopes some little consideration may be given to this aspect of the question, because he is afraid that Bengal's inexperience in up-to-date methods of river bad habit correction may lead it to believe that the cure is too easy for consummation.

We now drift to dredgers. The author has written, for the information of the Government of India, a long criticism of successes and faults in dredgers, and has no manner of doubt of being able to design a dredger to exceed current dredging practice, up to and exceeding if desirable 30,000 tons per hour per dredger on a draft of 5 feet. Readers are assured that 12,000 tons per hour is the usual practice on these drafts, but he is afraid that this subject has been left too much to dredging masters, excellent men though they are, who are constrained to (and we cannot blame them with the absurd equipment sometimes supplied them) pump dirty water so many hours a day, so many days a year, and so many years, for a pension.

Referring back again to Marks 1, 2, and 6, it will be seen how inevitably it follows that

any effort to correct the shape of our river water roads must bring about an immediate and great reclamation, such as would at once react on public prosperity, on revenue returns, and best of all perhaps on public health.

CHAPTER XIII.

Conclusions and Suggestions.

The author thought at one time it would be impossible to state that one rule of the behaviour of water was more important than another, because their totality has been accepted more or less as fate, but in conclusion he feels it would be well to point out that there is a difference of grade in importance of behaviour in respect of those things which we cannot control, and those which we can.

A study of the things we cannot control is as important as the study of those things which we can control, not because we can alter the former but because we may, by intelligent interpretation and correct anticipation, use the uncontrollable as tools to aid us in our management of the controllable. A bad workman complains of his tools and a moaning public have to blame themselves for most of the evils of life by having failed to recognise the dominating forces which are not doing those things we wish them to do. We are surrounded by thousands of forces constantly at work, willing to be our servants, but which, due to the extraordinary procrastination and evasion of responsibility which, in such a lot of cases, represents the public attitude, pass on their non-recognition paths, as regards their services to man, as unemployed.

This unemployed question as regards the forces available for waterway control, which must some day loom so very large in the transport and public prosperity situations of nations, is ready for immediate discussion and successful treatment.

Enough has been said about the straight-on law. It is always with us, always working, either for or against us. In water roads we have seen how we can enlist it on our behalf and what a big factor it can become in the world's happiness, which is the world's greatest desideratum. The straight-on law and the straight-down law between them dominate the bullet. Man must make the gun and, having made it, must direct it. So with waterways of which we are as much the master as the soldier is of his gun.

The title of this chapter warrants the assumption of a constructive policy. Here it is.

(1) The creation of a Waterway and Land Conservancy Trust for each country; such department to be supplied with sufficient funds for say five years, after which, in the manner of an Improvement Trust, it must be self-supporting and pay back all moneys and interest on such moneys within a limited period. It should be authorized to make only such profit as would be necessary for a fund for its own development, all future profit to be devoted to land

and waterway development and reduction of new ground rent. The Burma Boiler Commission of which the author was once secretary is run very successfully on these lines. The duties of the Trust beside that of waterways, land, and navigational improvement should be required to include a complete survey of the land shewing time movements as well as waterway and land movements.

The matter of the dredgers is one which cannot be repeated too often. An up-to-date dredger can conserve at least 60 miles of river a year at the very start and keep 300 miles of river a year in order when once things have been put right. One of these dredgers could crawl slowly over the beds and adjust the bottoms and sides as it did so. The time would not be in the work done but in the halting necessary to make sure of correct alignment and confluence depths.

The author has, he hopes, left no manner of doubt in his readers' minds that he is of opinion that river powers are forced to vagrancy by what appears to be a public indifference, which is apparently fed upon a total lack of recognition of the laws governing our rivers. He would like to remind his readers for the last time—

(1) That navigational transport, so vastly important to every land, has to be carried in

expensive bottoms in small quantities, at slow rates, at high prices, because we have neglected our river roads.

(2) That where erosion is allowed, agricultural security is at a discount, public contentment goes and political discontent comes with it. One may as well expect a fish to be happy when his water disappears as to expect human beings who exist upon the riverain to be satisfied when erosion stalks through their properties, thoroughly out of control, for although the humans cannot, may be, point to the cure, they feel the social distress as much as the owner of the bad tooth feels his, until he learns of the dentist, after which he demands the tooth out. The author would like to draw the erosion tooth from the body of Bengal, and the rest of the world, where existing.

A large part of Bengal and of Mesopotamia must be regarded as due to the sea beach habit of the sea working with the river eroded soils of their back lands. This is daily proceeding and it is time to call the halt we can. We cannot stop a little bottom movement, but this is, as far as we are concerned, negligible. The salt wedge, at present, is a retreating gate at big river mouths, making beach land greater every year. That such beach lands are suitable for human occupation is doubtful, and certainly

the author hopes that none of his readers will ever be compelled to try them.

It is desirable that river water should be thoroughly examined for soluble salts and other valuable things in suspension, and that we should find out the sap content (quality, quantity and nature) of local and desirable growths, so that nature may find ready to hand those things which she has shewn she is willing to use, when she can get them.

The subject of non-true bay sea coasts is one requiring a lot of investigation and will be the subject of another book if, and when, opportunity offers.

The author is keen to repeat that soluble things are, in rivers, carried not in solution, but in suspension, although, at the river mouth, NA CL is what it is.

LIST OF ILLUSTRATIONS ON FOLLOWING PAGES

Also six highly interesting sketches prepared by Captain G. R. Simpson showing River Routes which have been abandoned

A supposititious river with tributaries

FIG. 1.
As it is

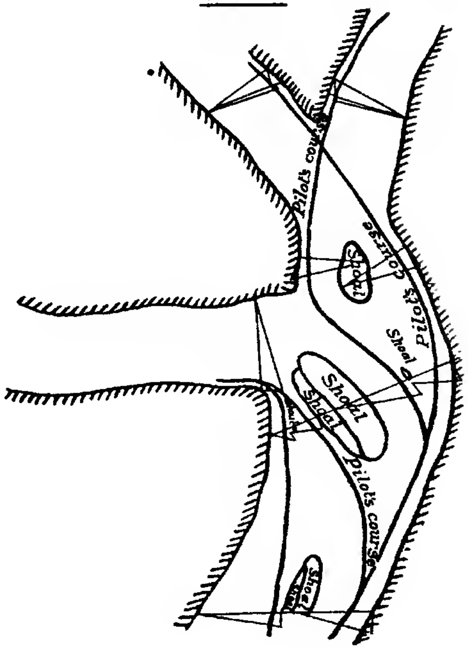
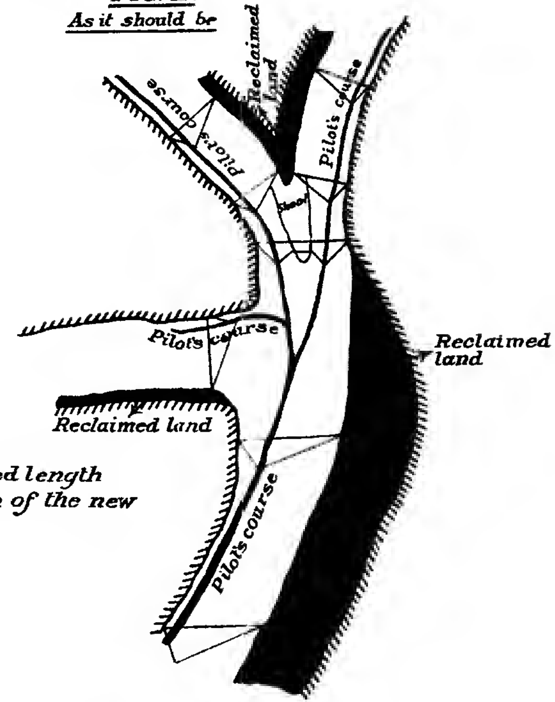


FIG. 2.
As it should be



Note the decreased length and increased depth of the new pilot's course.

(1)

Comparative Sections of controlled and uncontrolled river beds.

Curves are those of River Banks.

FIG. A

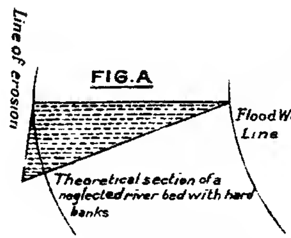
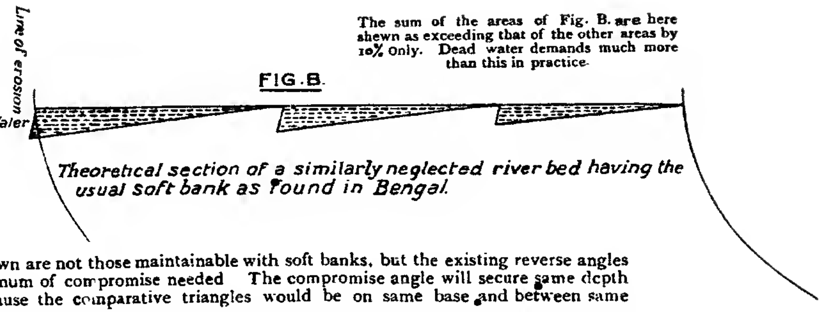


FIG. B

The sum of the areas of Fig. B. are here shewn as exceeding that of the other areas by 10% only. Dead water demands much more than this in practice.

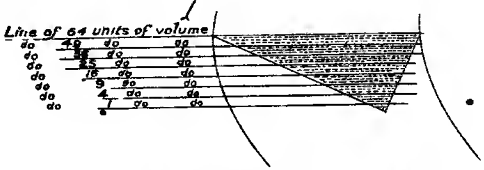


Theoretical section of a similarly neglected river bed having the usual soft bank as found in Bengal.

Theoretical angles shewn are not those maintainable with soft banks, but the existing reverse angles shew exactly the mi imum of compromise needed The compromise angle will secure same depth for equal volume because the comparative triangles would be on same base and between same parallels

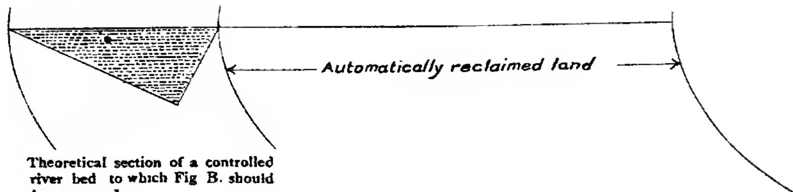
As the areas of these sections vary as the square of the depth, it is obvious one gets a maximum of depth for low water and a minimum of depth for high water, so that shortage and floods are both provided for with maximum advantage.

FIG. C



Theoretical section of a controlled river bed to which Fig. A. should be converted.

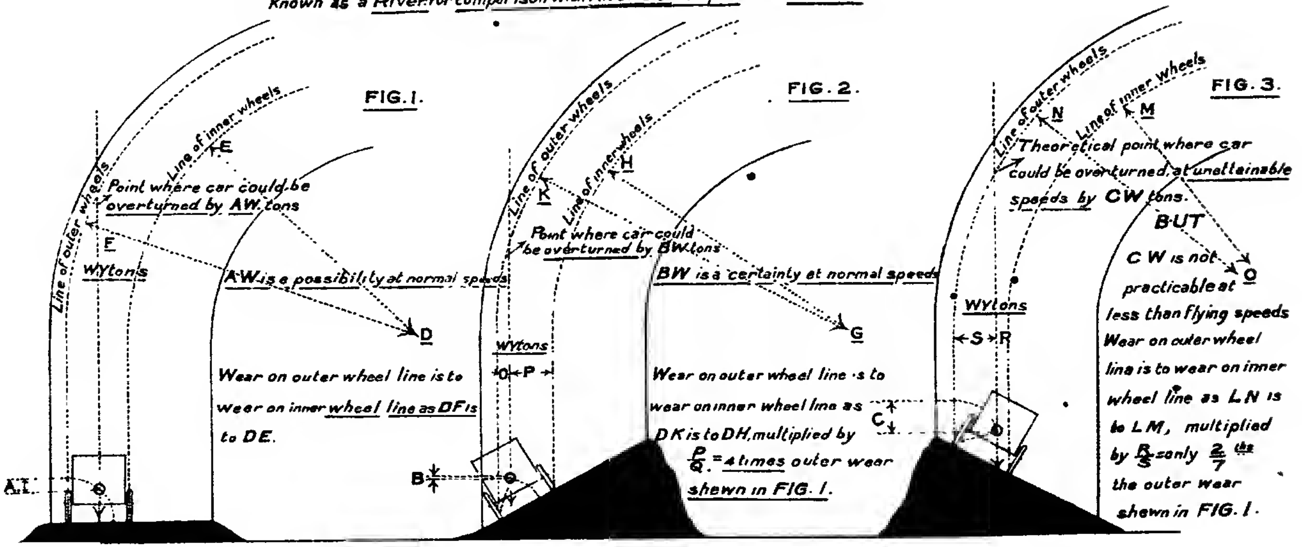
FIG. D



Theoretical section of a controlled river bed to which Fig B. should be converted

DRY ROADS & DRY VEHICLES.

Drawn to shew how these familiar facts are applicable to the unfamiliar case of the water road known as a River for comparison with River Bed slopes see Mark 2.



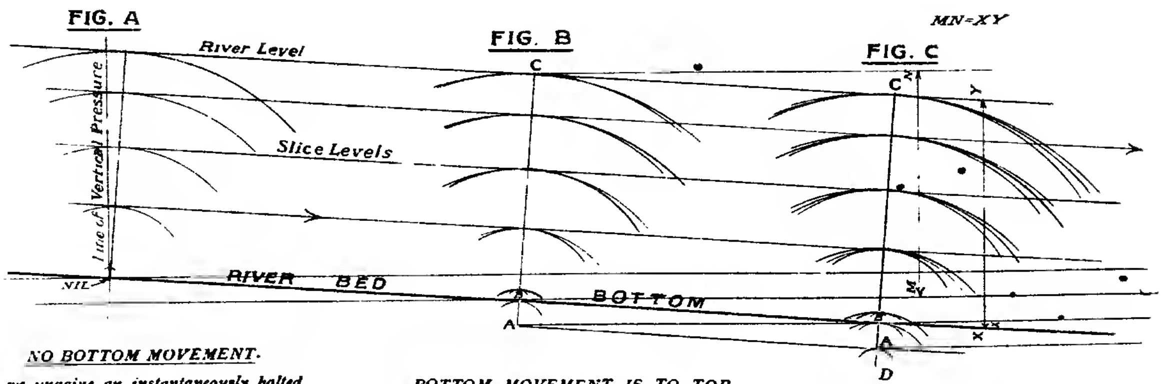
O is centre of gravity of car in each case.

Car weighs W. tons.

A. B. & C are any suitable linear units.

The wear on the outer wheel line of FIG. 2. is 14 times that on the outer wheel line of FIG. 3.

DRAWN TO SHEW DEVELOPMENT OF RIVER BOTTOM MOVEMENT. A B IS SLOPE. A D IS PERCOLATION



NO BOTTOM MOVEMENT.

If we imagine an instantaneously halted river, with a concrete bottom, the radiu of each curve would represent the potential relative velocity at each tangent slice level.

BOTTOM MOVEMENT IS TO TOP MOVEMENT AS AB TO AC.

With a concrete bottom, the radius of each larger curve would represent the actual relative velocity at each tangent slice level.

BOTTOM MOVEMENT IS TO TOP MOVEMENT AS DB TO DC.

With a usual soft bottom the radius of each largest curve would represent the real velocity at each tangent slice Level.

DENSITY & TEMPERATURE EFFECT ON SILT.

FIG. I.
Temp. 200. F.

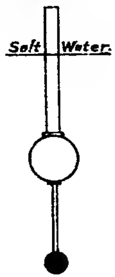


FIG 2.
Temp. 60. F.

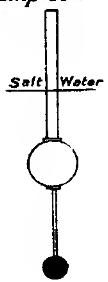


FIG 3.
Temp 40. F

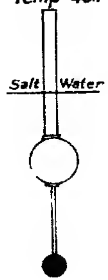


FIG. 4.
Temp. 80 F.

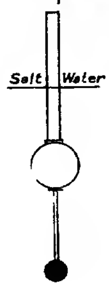


FIG. 5.
Temp. 40 F.

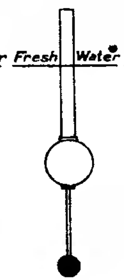


FIG 6.
Temp. 80. F.

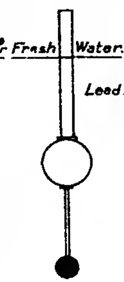
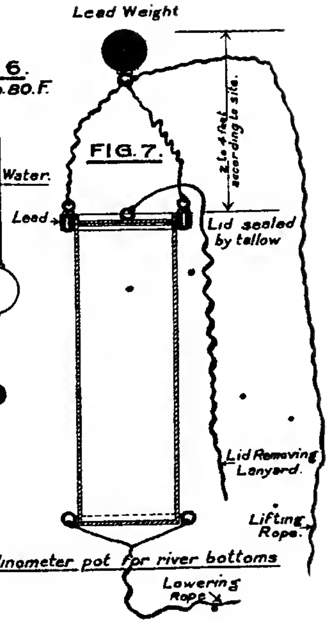


FIG. 7.



The author's salinometer pot for river bottoms

A supposititious River. Narrowed to shew bed sides chiefly.

FIG. 1.

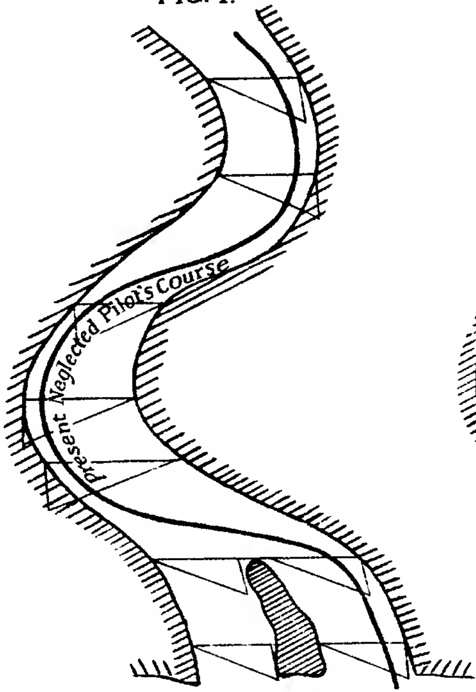
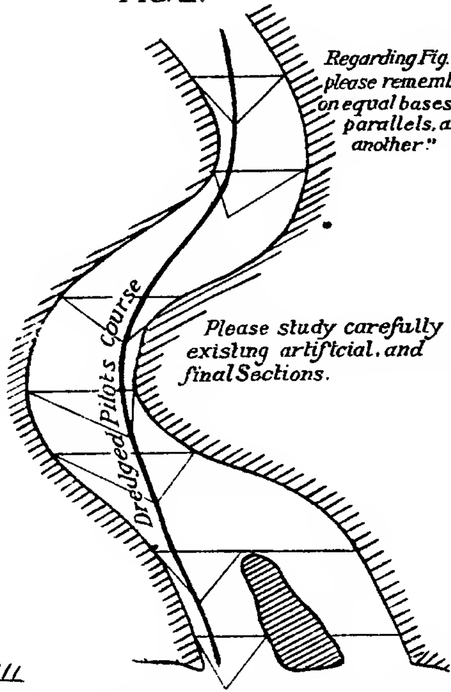


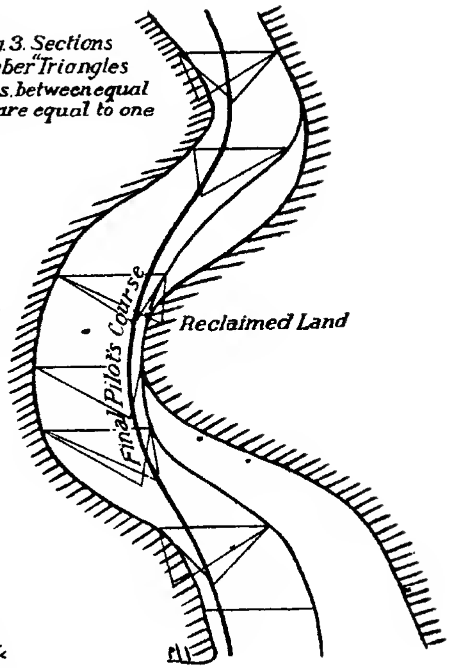
FIG. 2.



Regarding Fig. 3. Sections please remember "Triangles on equal bases, between equal parallels, are equal to one another."

Please study carefully existing artificial, and final Sections.

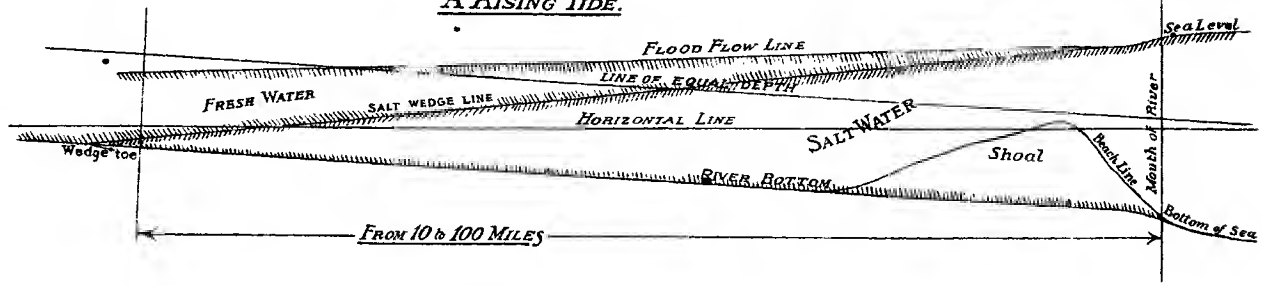
FIG. 3.



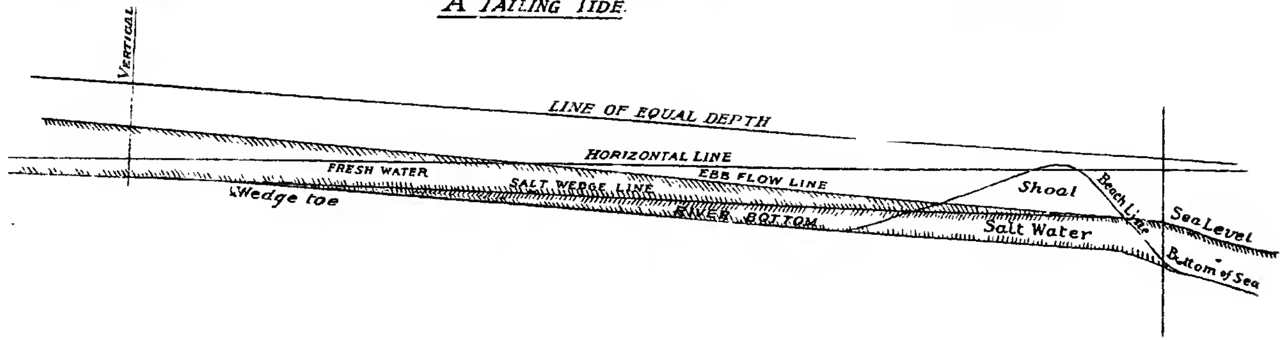
Dredging would only be necessary at key points during alteration period. The river would de the rest.

DIAGRAM SHEWING A VERTICAL VIEW OF ACTION OF TIDE AT A RIVER MOUTH

A RISING TIDE.

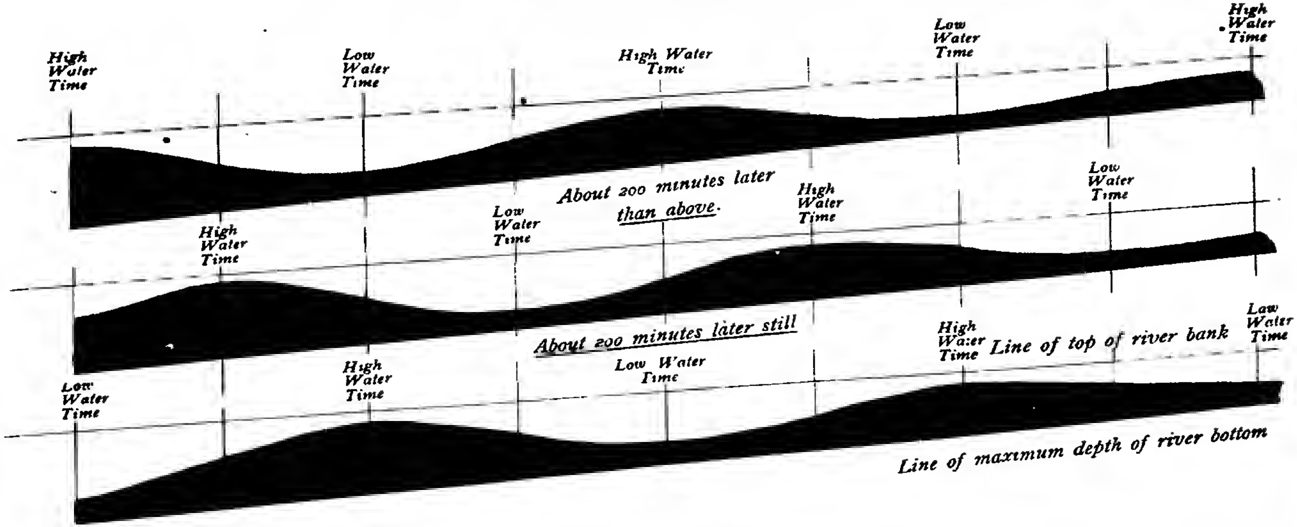


A FALLING TIDE.



<u>According to Time</u> (normal conditions)

<u>Form of Tidal Expression in a big River.</u>



Note why River must run up <u>after High Water</u> and must run down after low water.

The tide time <u>interval is different</u> for every River } *<u>But each River</u>*

The distance interval, <u>crest to crest, is different for</u> every River } *<u>daily declares itself.</u>*

The time between one crest and the next crest then existing, up the river, of same time, will be entirely due to local conditions. This error is nearly permanent, but any <u>one place, having established its error</u>, will fluctuate at almost true tide rates.

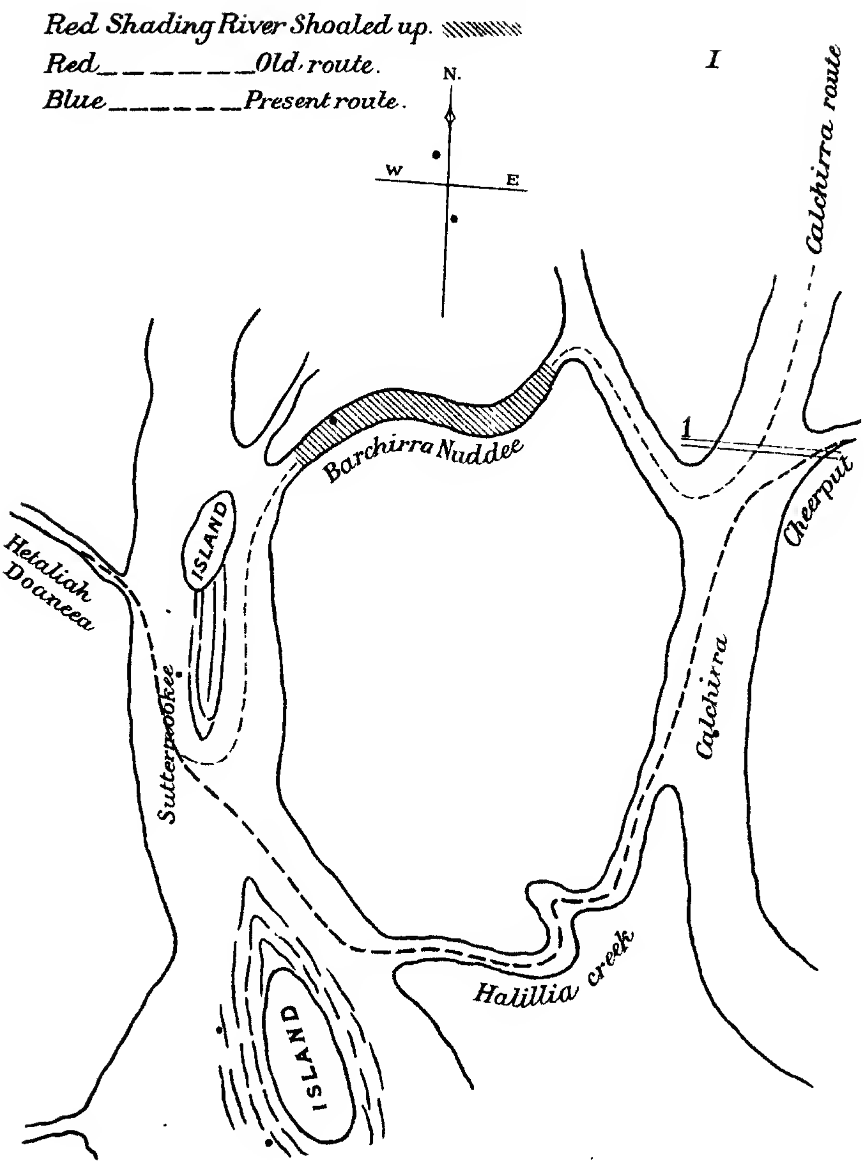
Note the difference and the cause of <u>shape of curve on either</u> side of mean high and low water tide times.

NOTE.

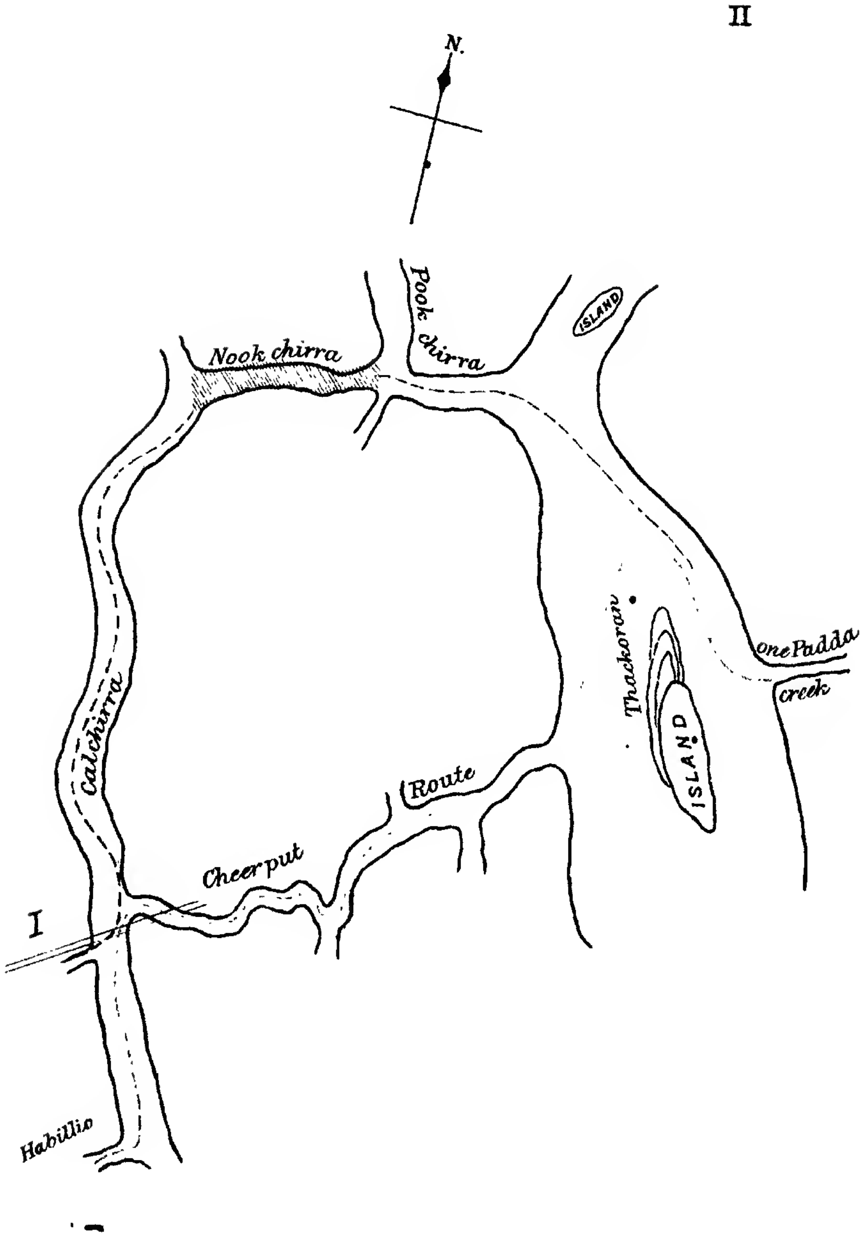
The following six sketches, prepared by Captain G. R. Simpson, Marine Superintendent of the I. G. N. & R. Co., etc., show River Routes which the India General Navigation Company Ltd. have been obliged to abandon owing to the cross rivers, *i.e.*, the E. and W. ones, closing up partly through natural causes as incidental to cross rivers, and partly, and in some cases wholly, to reclamation works.

The author here wishes to express his deep sense of obligation to Captain Simpson for having prepared these River Route Sketches and allowing him to use them.

BARCHIRRA ROUTE.

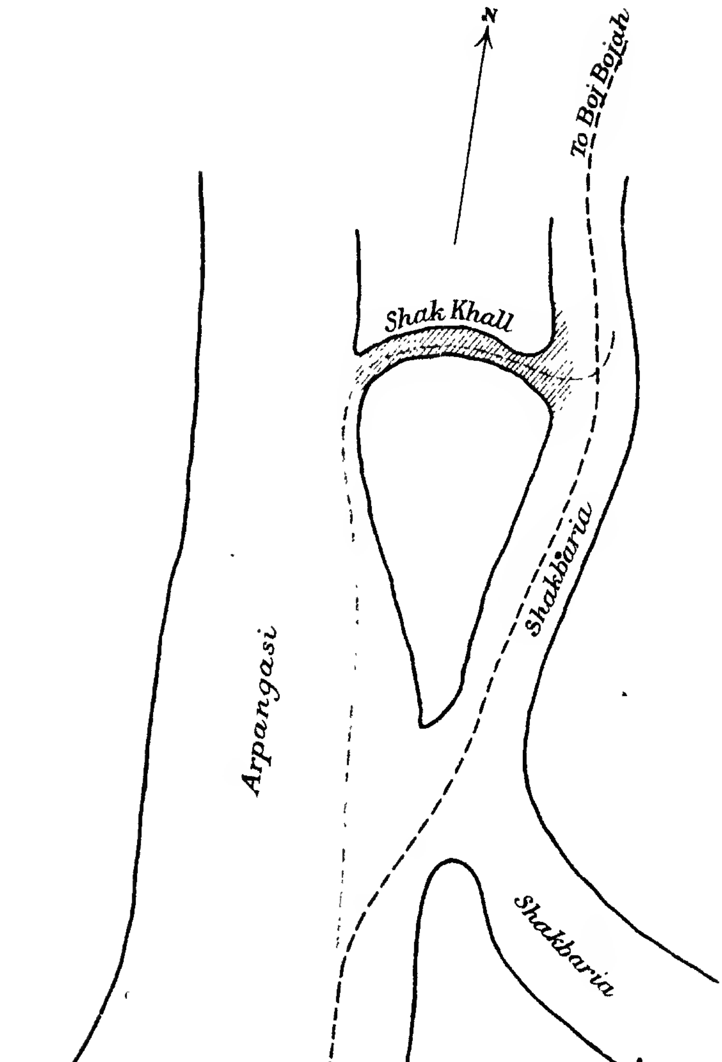


NOOK CHIRRA ROUTE

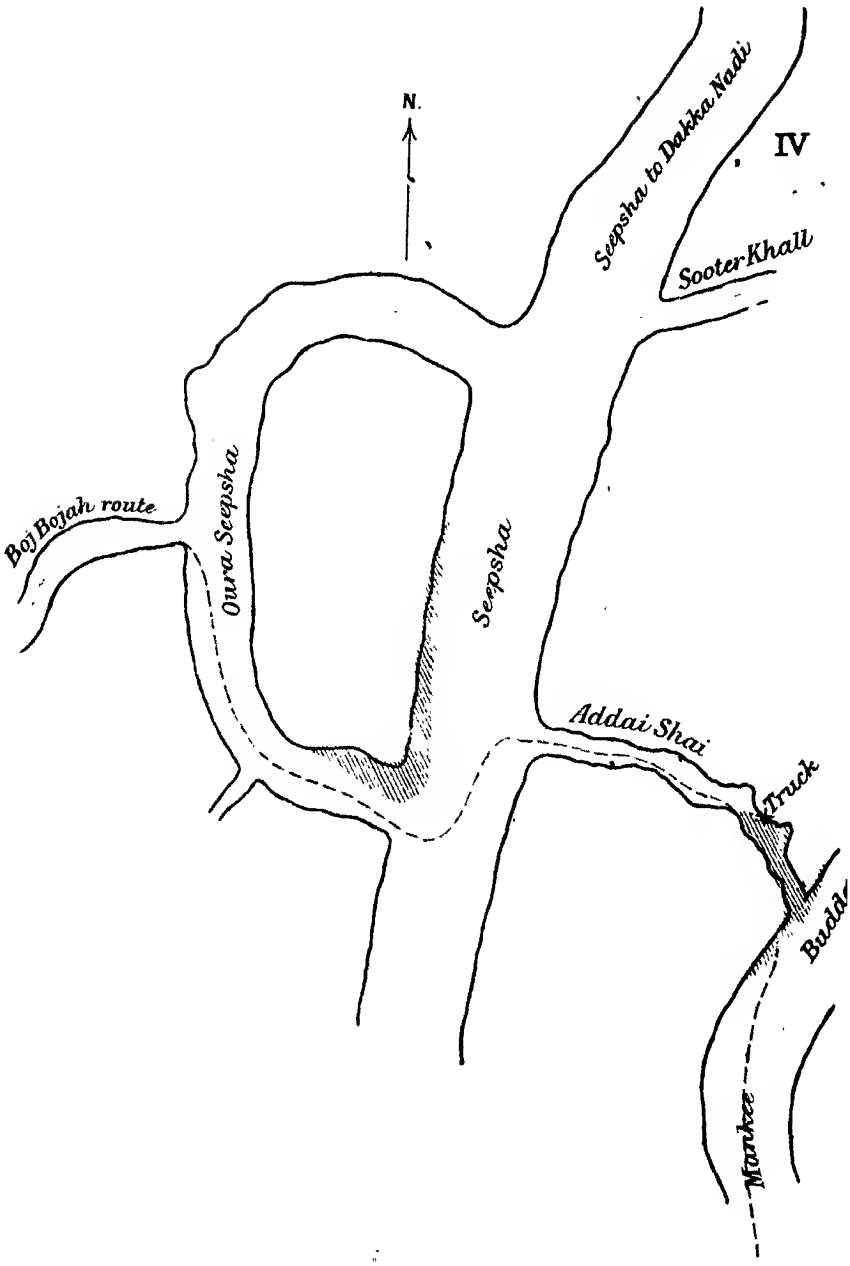


GHAU KHALL ROUTE

III

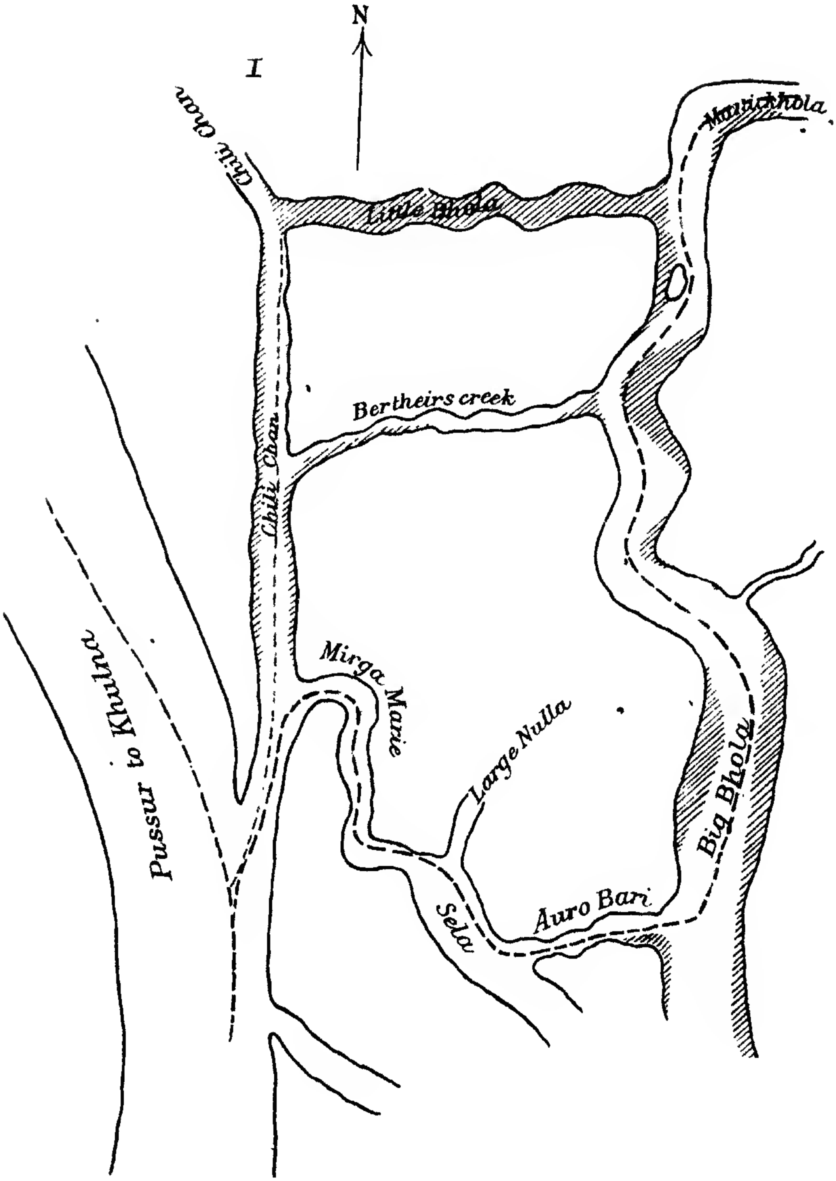


ADDAI SHAI ROUTE

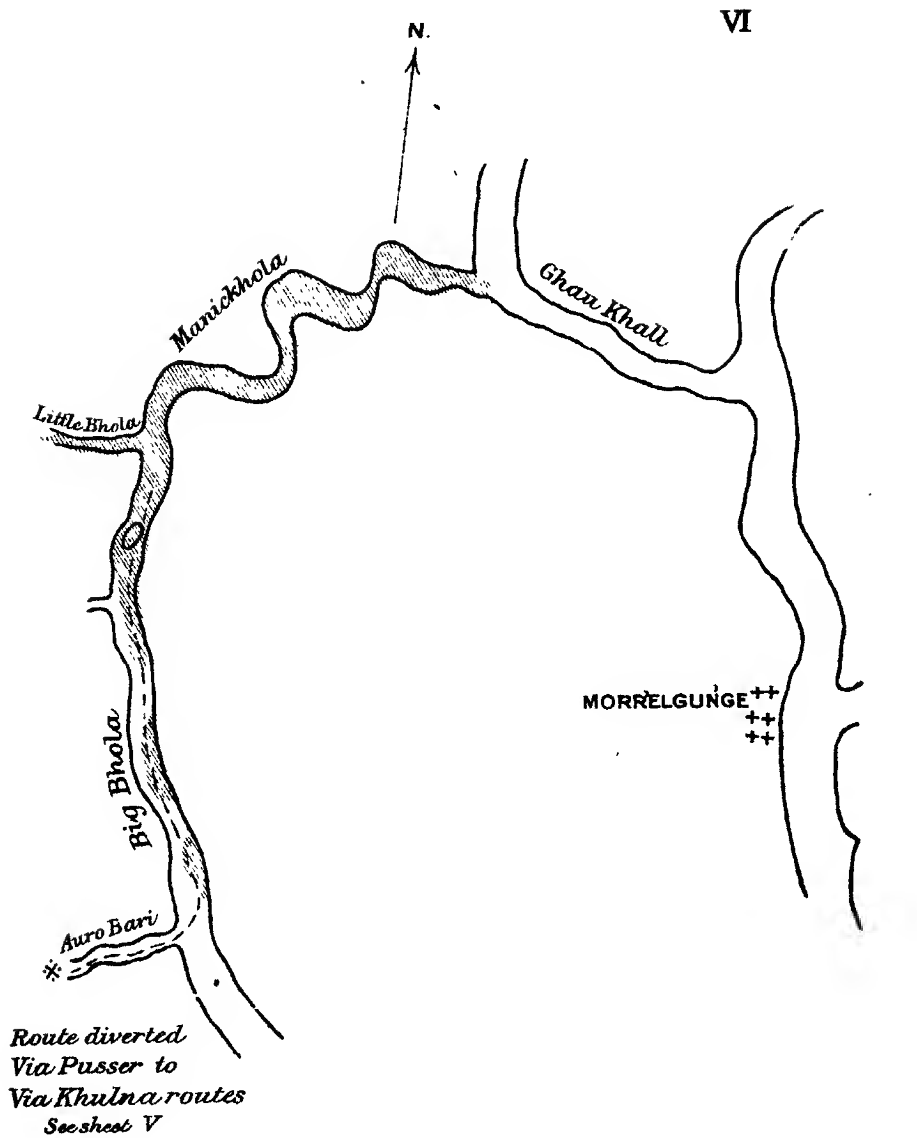


CHILICHAN & BHOLA ROUTE

V



BHOLA ROUTE



VI
N.
Manickhola
Ghau Khall
Little Bhola
Big Bhola
MORRELGUNGE
Auro Bari
Route diverted
Via Pusser to
Via Khulna routes
See sheet V

Printed by
W. NEWMAN & CO., LTD.,
at their Printing Works,
MEREDITH LANE CALCUTTA.